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WAR DEPARTMENT

U.S. Dept. of Army

TECHNICAL MANUAL

WELDING

April 24, 1942

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TECHNICAL MANUAL

WELDING

CHANGES No. 1 } WAR DEPARTMENT, WASHINGTON, March 6, 1943.

TM 1-430, April 24, 1942, is changed as follows:

8. **Oxyacetylene flames.**

* * * * * * *

a. The neutral flame (fig. 9①) **is** produced by burning acetylene with oxygen in such proportions as to oxidize all particles of carbon and hydrogen in the fuel gas (acetylene), resulting in a flame temperature of approximately **5,850° F.** This flame is * * * and water vapor.

b. The carbonizing or * * * in air alone. **The carburizing flame temperature is approximately 5,700° F.**

c. An oxidizing flame * * * cone just disappears. **The oxidizing flame temperature is 6,300° F.**

* * * * * * *

[A. G. 062.11 (2-22-43).] (C 1, Mar. 6, 1943.)

39. **Welding carbon steels.**

* * * * * * *

d. High carbon steels.—The high carbon * * * degree of hardness. When welding the **high** carbon steels by means of the oxyacetylene process, the flame must be carefully adjusted **to carburizing to produce a sound weld.**

[A. G. 062.11 (2-22-43).] (C 1, Mar. 6, 1943.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

J. A. ULIO,
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The Adjutant General.

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TECHNICAL MANUAL No. 1–430

WAR DEPARTMENT, WASHINGTON, April 24, 1942.

WELDING

SECTION I

OXYACETYLENE WELDING EQUIPMENT

*This manual supersedes TM 1–430, February 20, 1941.

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1. **General.**—The joining of metal parts by welding consists of fusing the material together while it is in the plastic or molten state. There are several ways of producing this fusion and the various processes may be outlined as follows:

a. Forge welding is accomplished by heating the ends of metal parts in a forge fire in which coal, coke, or charcoal is used as a fuel. The ends to be joined are heated to a plastic state, then united by the application of mechanical pressure or blows. Forge welding is confined to welding of wrought iron and steel. Several steel alloys, as well as the other weldable metals, cannot be satisfactorily joined in this manner.

b. Blowpipe welding is accomplished by heating the ends or edges of metal parts to a molten state with a high temperature flame. This flame is produced with a blowpipe or torch, burning a special gas such as acetylene, or hydrogen, with pure oxygen. The metal, when in a molten state, literally flows together to form a union without the application of mechanical pressure or blows. Blowpipe welding is used extensively in both the manufacturing and repair fields and may be applied to all weldable materials.

c. There are several forms of electric welding in which electrical energy is converted into heat for welding purposes. Electric arc welding, electric resistance welding, and atomic hydrogen arc welding are the methods in general use.

(1) Electric arc welding is a fusion method in which the heat liberated in the arc stream and at the arc terminal is used to melt or fuse the metal at the joint. Arc welding is employed for both manufacture and repair and can be satisfactorily used in the joining of all weldable metals. The melting metal flows together to effect a union without the application of pressure in any form. There are four different forms of arc welding, each being particularly adapted to certain types of work:

(*a*) *Metallic arc process.*—In this method the welding rod is used as one of the electrodes, while the work is made the other. An arc formed between these electrodes simultaneously fuses the rod and the work at the joint. The melting metal from the rod is carried through the arc and deposited in the melting metal of the work to make the weld.

(*b*) *Carbon arc process.*—In the carbon arc method a carbon rod is used as one of the electrodes and the work the other. The work, at the joint, is melted or fused by the resulting arc. In case additional metal is required, a welding rod is fed into the joint and fused simultaneously with the work to make the weld.

(*c*) *Arc torch process.*—This method employs two carbon electrodes, between which an arc is formed. This arc flame is used to fuse the work at the joint in the same manner as a blowpipe flame, and filler metal is added by means of a welding rod.

(*d*) *Atomic hydrogen arc process.*—This system employs two tungsten electrodes. An arc is maintained between the ends, and a stream of hydrogen gas is passed into the arc and around the electrodes. The heat of the arc breaks up the molecules of hydrogen into atoms, which recombine outside the arc to form molecular hydrogen again. The intense heat liberated by the atomic hydrogen as it recombines is used to fuse the metal as in blowpipe welding.

(2) In electric resistance welding, a low voltage and high amperage current flows through heavy copper electrodes with comparative freedom until it reaches the work placed in its path. Intense heat is generated at this point due to the resistance of the material to be welded, which quickly raises the metal to the welding temperature. At the proper time pressure is applied to make the union. The principal application of this method of welding is in the manufacturing field, for parts fabricated of sheet metal.

d. Thermite welding utilizes the heat liberated by the chemical reaction between aluminum powder and iron oxide. A part of this mixture, which is known as thermite, is brought to a high temperature and ignited, causing a reaction which continues through the entire mass. The spreading of this reaction is due to the aluminum combining with the oxygen of the iron oxide to form both highly superheated aluminum oxide and free iron in the form of liquid steel. The extremely high temperatures produced are estimated to be approximately 5,000° F. although positive measurement is impossible. The reaction is produced in a crucible, and the highly superheated steel is poured around the sections to be welded which have previously been brought to red heat. The high temperature of the molten mass causes the parts to unite with the Thermite steel and, when cooled, produces a homogeneous section. The principal field for this method of welding is in the repairing of heavy sections of iron or steel, such as locomotive frames, heavy crank shafts, boat impeller shafts, rails, etc.

2. Oxyacetylene welding process.—*a.* The oxyacetylene process of welding is a method in which acetylene and oxygen gas are used to produce the welding flame. The temperature of this flame is approximately 6,300° F. and sufficiently high to melt any of the commercial metals to effect a weld. When the oxyacetylene flame is applied to the ends or edges of metal parts, they are quickly raised

to a melting state and flow together to form one solid piece upon solidifying. Usually some additional metal is added to the weld, in the form of a wire or rod, in order to build up the seam to a greater thickness than the base metal. In the case of very light sheet, the edges to be joined may be flanged and when melted down will give the necessary thickness in the weld metal. This additional

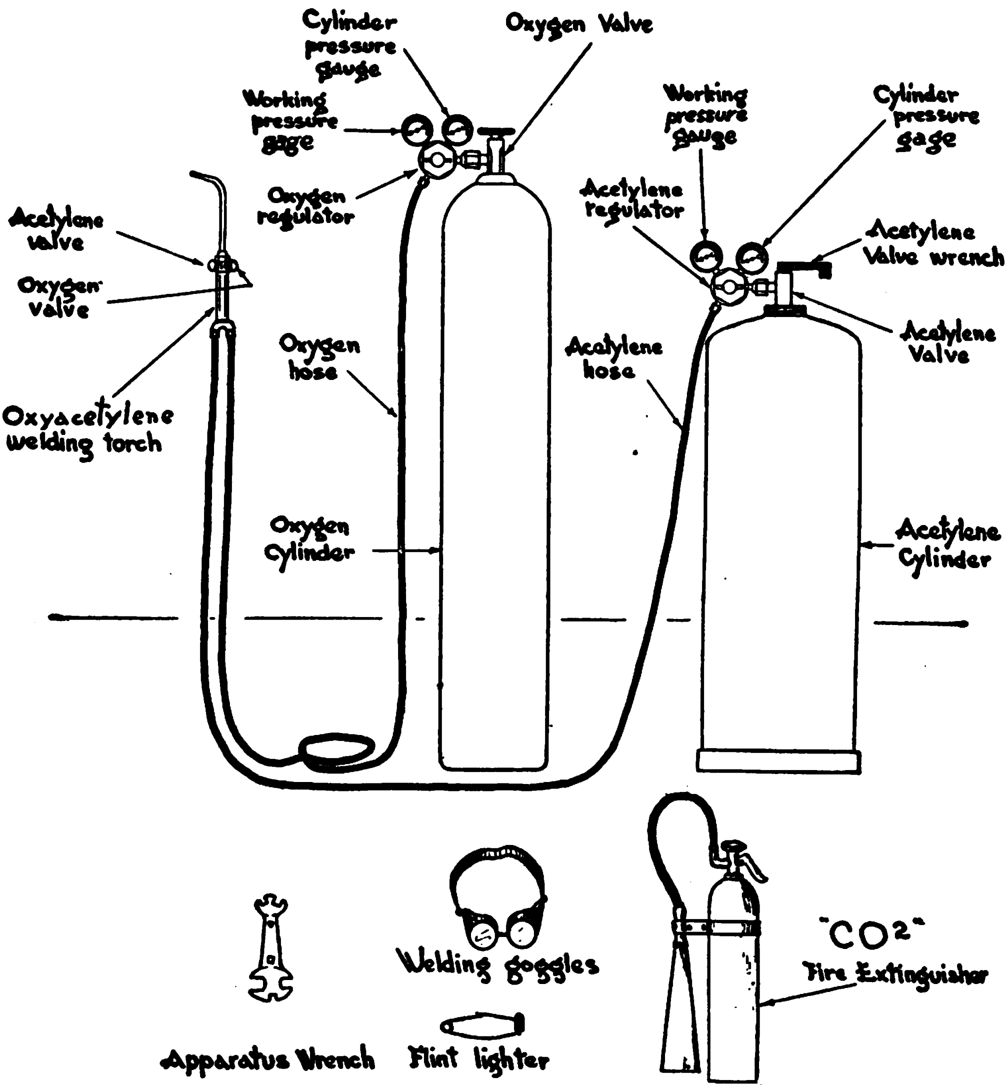


FIGURE 1.—Portable oxyacetylene welding outfit.

thickness in the weld is necessary to the strength of the joint, as the weld is cast metal and, in general, does not possess as fine a grain structure and fiber as the base metal unaffected by the welding heat. The strength of a weld in any metal depends largely upon the manner in which it is made. If the metal is correctly prepared and the proper flame used, a sound, dependable weld is obtained in all weldable metals by this method.

b. The oxyacetylene welding equipment may be either portable or stationary, depending upon the class of work to be done. A portable apparatus is shown in figure 1 and consists of a supply of acetylene and oxygen gas in cylinders; acetylene and oxygen pressure regulators complete with pressure gages and connections; a welding torch with mixing head, tips, and connections; two lengths of hose, with adapter connections for the regulators and torch; an apparatus wrench; a pair of welding goggles; a safety flint and file gas lighter; and a suitable fire extinguisher. The stationary equipment is similar to the portable set except that acetylene and oxygen are piped to the welding stations from a gas supply, which consists of a number of cylinders connected together by means of a manifold, equipped with a master regulator for each group of cylinders. The master regulators control the flow of gas and maintain a constant pressure of each at the welding stations. In some cases an acetylene generator is used to supply acetylene gas for the installation.

3. **Acetylene gas.**—*a.* Acetylene is the fuel used in the production of the high temperature oxyacetylene flame. It is a compound of carbon and hydrogen (C_2H_2) which indicates that 2 atoms of carbon are combined with 2 atoms of hydrogen in its chemical structure. The difference in the atomic weight of the two elements (carbon 12 and hydrogen 1.008) gives it a content of 92.3 percent carbon and 7.7 percent hydrogen. Acetylene is without color, has a distinctive odor that is easily detected even when strongly diluted with air, and is nauseating when impure. It is a highly combustible gas when mixed with air or oxygen; the range of explosive mixtures being from 97 percent air and 3 percent acetylene to 18 percent air and 82 percent acetylene. It has a flame speed of 330 feet per second and when mixed with oxygen or air must flow from the torch at a velocity greater than the flame speed to prevent it burning back to the source of supply.

b. Acetylene is a stable compound under low pressure at normal temperature when free from air, but becomes unstable when compressed in an empty container to a pressure exceeding 15 pounds per square inch. Under a pressure of 29.4 pounds per square inch it becomes self-explosive, and a slight shock is apt to cause it to explode even when no air or oxygen is introduced. The danger of storing acetylene under high pressure has been overcome, however, by dissolving it in acetone which has the property of absorbing or dissolving large quantities of acetylene under pressure. A cylinder containing the right amount of acetone can be charged to a pressure of

250 pounds per square inch with safety under normal temperature and handling conditions.

c. Acetylene is a manufactured gas produced by dissolving calcium carbide in water. Calcium carbide is a compound of carbon and calcium (CaC_2) which is prepared by the fusing together of limestone and coal in an electric furnace. When calcium carbide comes in contact with water it absorbs the water rapidly and is decomposed. The carbon combines with the hydrogen to form acetylene, and the calcium combines with the oxygen to form slacked lime or calcium hydrate. One pound of pure, clean carbide will yield about 5 cubic feet of acetylene, but it is rated commercially at 4½ cubic feet per pound. Acetylene is sold by weight and contains 14.5 cubic feet per pound.

4. Oxygen gas.—*a.* Oxygen is a nonmetallic element found in practically all natural substances, either in the free state or combined with other elements. It is one of the principal constituents of the atmosphere and water. The atmosphere is made up of approximately 21 parts of oxygen and 78 parts of nitrogen, the remainder being rare gases. The combination of oxygen and nitrogen in the atmosphere is not a chemical one as both gases exist in a free state. Water is a chemical compound of 2 parts of hydrogen and 1 part of oxygen by volume. Oxygen is a very active element and will combine with practically all materials under suitable conditions, sometimes with destructive results. Carbon and hydrogen have a strong affinity for oxygen, and when mixed in the right proportions the presence of a flame or spark will produce rapid combustion. Grease and oil are also highly combustible in the presence of pure oxygen. Some of the metals are greatly affected by oxygen and under suitable conditions will burn readily in its presence. Rust on ferrous metals, the dark discoloration of copper, and the corrosion of aluminum all are due to the action of oxygen in the atmosphere, this action being referred to as oxidation.

b. The value of oxygen in welding lies in the fact that it supports combustion of the fuel gas used in the process involved. It is a colorless, odorless, and tasteless gas having an atomic weight of 16. Its specific gravity, as compared with air at 32° F. and normal atmospheric pressure, is 1.1053. The weight per cubic foot is 0.08926 pound, thus requiring 11.203 cubic feet to equal 1 pound.

c. Oxygen is obtained for commercial purposes by either of the following methods:

(1) The liquid air process furnishes the larger part of the oxygen used for welding purposes. In this process the atmosphere is liquefied

by compression and cooling to a point where the gases of which it is composed may be separated by fractional distillation. The separation of these gases is similar to the separation of water and alcohol; that is, the gas which has the lowest boiling point passes off into its gaseous form when the temperature of the liquid is raised, thereby leaving the gas which has the higher boiling point still in a liquid state. As previously stated, oxygen and nitrogen make up the major part of the atmosphere and are, therefore, the gases to be considered. As the boiling point of nitrogen is −321° F. and that of oxygen −297° F., the nitrogen will change to its gaseous form first, when the temperature of the liquid is raised. This leaves the oxygen remaining in a liquid state. After separation, it is changed to its gaseous form by a further rise in temperature.

(2) The electrolytic process of obtaining oxygen from water consists of separating hydrogen and oxygen by passing a direct electric current through water in an electric cell, to which an acid or alkali has been added. The electric current causes the water to break down into its chemical elements of hydrogen and oxygen. The oxygen collects at the positive terminal while the hydrogen collects at the negative terminal, and each gas is passed off to its respective container through suitable pipes.

5. Acetylene and oxygen regulators.—*a.* The regulators or reducing valves are mechanical instruments used to reduce the high pressure of the gases as they flow from their respective containers. These units also supply the gases to the torch at a constant pressure and volume as required by the torch tip or nozzle.

b. There are several different makes of regulators in use. Although slightly different mechanically each operates with a diaphragm control. Practically all regulators are either of the nozzle or stem type and are obtainable for either single or two stage pressure reduction. Figures 2 and 3 show the operating principles of both single and two stage units and the arrows in these figures indicate the flow of gas. The two-stage regulator is preferable for operation on single cylinders, while the single-stage type may be used at individual stations of a stationary installation. Regulators used on cylinders are usually equipped with two pressure gages. A high pressure gage indicates the pressure of gas in the cylinders and a low pressure gage gives the pressure of the gases flowing to the torch. The high pressure gages on oxygen regulators are graduated in pounds per square inch, from 0 to 3,000, and in cubic feet, from 0 to 220. The working pressure gage for oxygen welding regulators is usually graduated in pounds per square inch, from 0 to 100, although oxygen regulators which are

used for heavy duty cutting, etc., have the working pressure gage graduated in pounds per square inch up to 400.

c. Acetylene regulators are of the same general design as the oxygen regulator, although they are not made to withstand such high pressures. The high pressure gage indicates pressure only up to a maximum scale value of 400 pounds per square inch. Maximum scale values on various working pressure gages range from 30 to 50 pounds per square inch; dial graduations have values of ½ to 2 pounds per square inch per division of the scale, depending upon the model of gage.

d. Regulators used in installations where the gases are piped to the welding stations have one gage only, which is used to indicate the pressure of gases flowing through the hose to the torch.

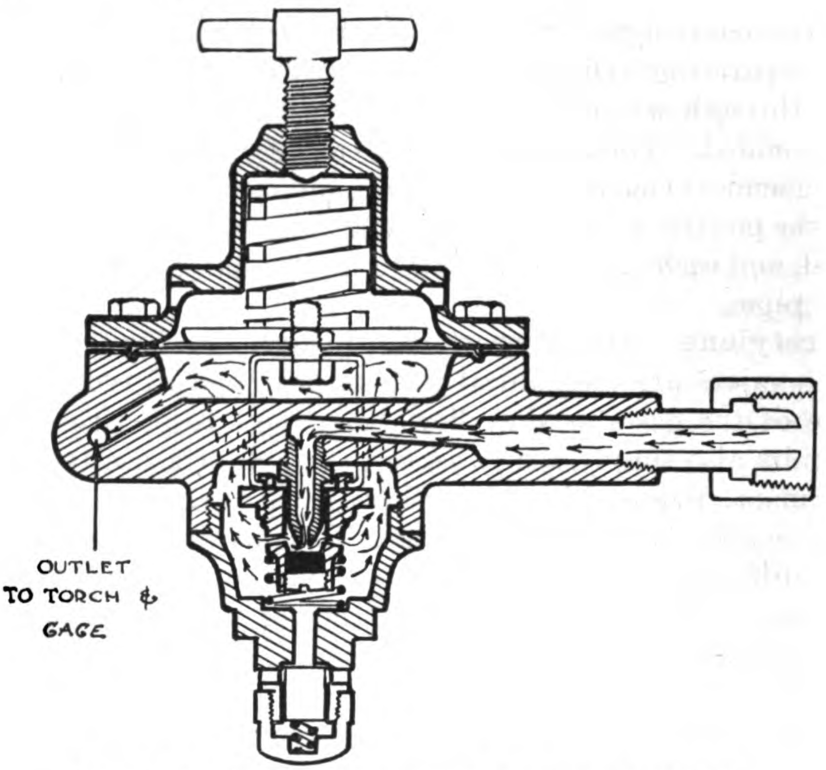


FIGURE 2.—Single-stage pressure reduction gas regulator.

e. Some regulators have a safety device to relieve excess pressure in the low pressure chamber due to a flashback or a leaking valve seat. This device may be either an automatic valve or a frangible disk connected to the low pressure chamber. The frangible disk is contained in a cup-shaped body attached to the diaphragm chamber, and will blow out before the pressure becomes high enough to injure the Bourdon tube in the low pressure gage or the diaphragm and hose. The automatic valve opens to relieve the excess pressure and reseats immediately after the pressure becomes normal.

f. Some makes of regulators have a rubber diaphragm reinforced with fabric, while others are fitted with a highly tempered nonrusting metal alloy. The seats are either composition or hard rubber, chemically treated to preclude spontaneous combustion.

g. The pressure gages are of the Bourdon tube type, consisting of a cup-shaped metal case, Bourdon tube, end piece, link, sector arm, pinion post, indicating hand, graduated dial, and socket. The case is formed of cast or pressed brass, steel, or iron, and is the housing

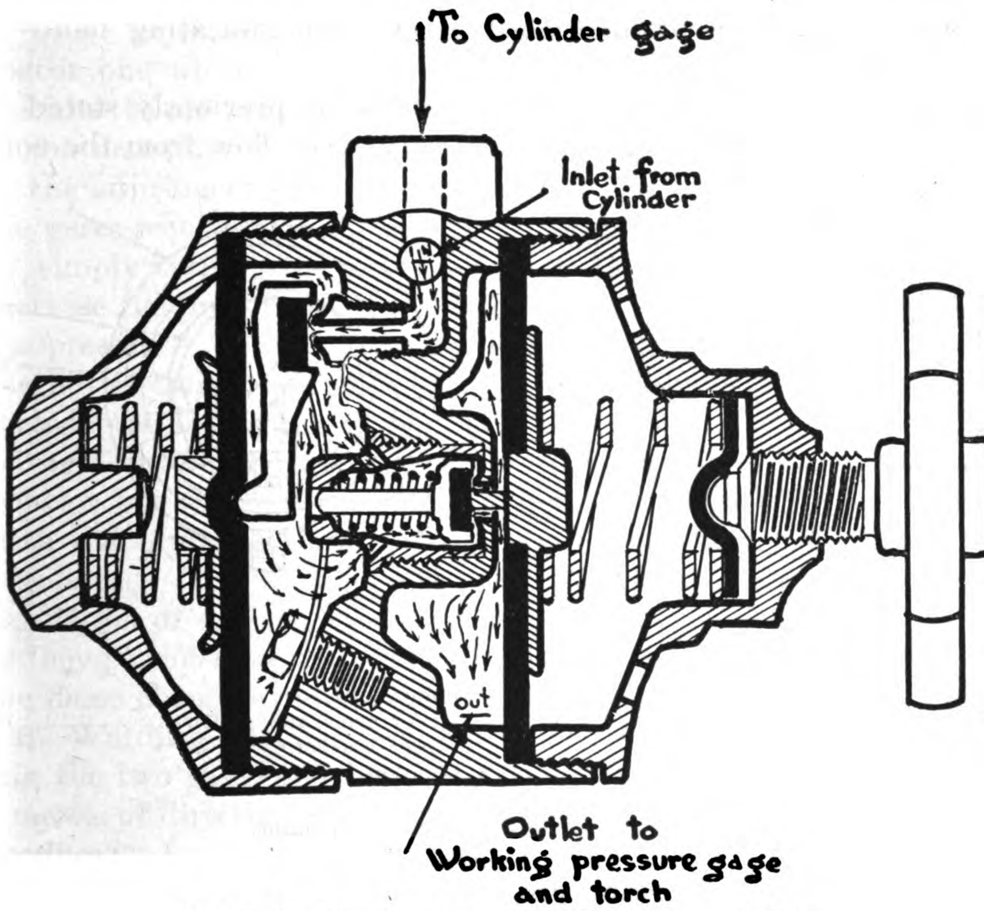
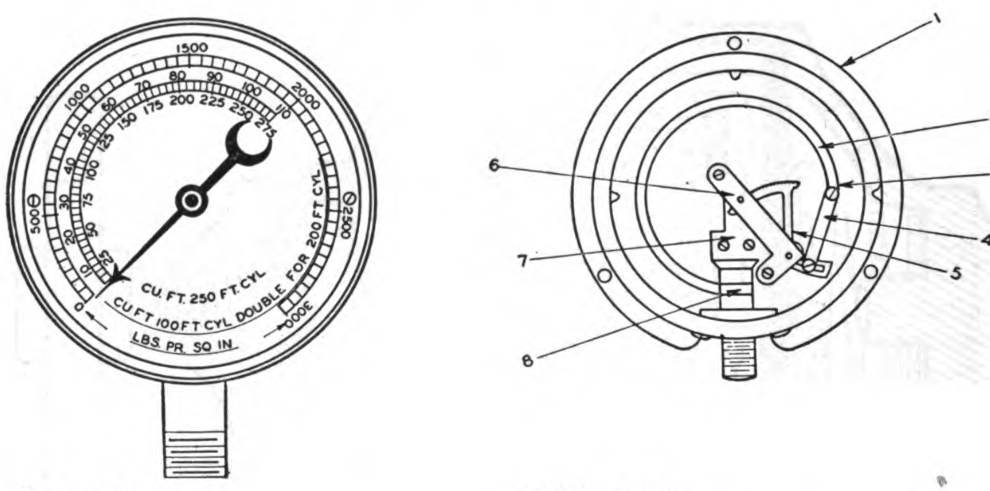


FIGURE 3.—Two-stage pressure reduction gas regulator.

for the actuating mechanism. A glass cover plate is mounted over the dial and held in place by means of a threaded metal ring. Some means of safety release is provided which will insure the escape of gas in case of a leak or rupture of the Bourdon tube, and at the same time prevent the danger of blowing out the cover glass, which would endanger the operator. This safety release consists of a thin metal plate, usually mounted in the back of the case and held in place by means of a spring or screws which will permit it to open easily in the case of pressure. The Bourdon tube is elliptically shaped and

curved to fit the case. One end is soldered into the socket which connects to the regulator, while the other end is sealed with a fitting to which the link that operates the sector arm and pinion is attached. Figure 4 shows the operating mechanism of a typical pressure gage. The socket (8) is threaded and provides a connection to the regulator through which the gas passes to the Bourdon tube (2), which causes the tube to tend to straighten. This movement is transmitted through the link (4) to the sector arm (5) and thence to the pinion post (6) on which the indicating hand is mounted. When the pressure is relieved, the tube resumes its normal position and the indicating hand is returned to 0 by this movement.

h. The primary purpose of the regulator as previously stated is to reduce the high pressure of the gases, as they flow from the con-



1. Gage case.
2. Bourdon tube.
3. End piece.
4. Link.
5. Sector arm.
6. Pinion post.
7. Sector arms and pinion post bracket.
8. Bourdon tube socket.

FIGURE 4.—Pressure gage for gas regulator.

tainers, to a desired working pressure at the torch. When the tank valve is opened, the gas enters the regulator through the inlet connection and flows into the passage leading to the high and low pressure chambers. The high pressure gage, being attached to the high pressure chamber, indicates the gas pressure in pounds per square inch contained in the cylinder. In order to permit the gas to enter the low pressure chamber the adjusting screw is turned to the right. This action compresses the diaphragm control spring, forcing the diaphragm against the yoke or pin, which communicates with the seat holder. Pressure causes the seat to move away from the nozzle and permits the gas to flow into the low pressure chamber, then through

the hose to the torch. The pressure of gas flowing through the regulator to the torch is indicated by the working pressure gage attached to the low pressure chamber. When the torch valves are closed, pressure builds up in this low pressure chamber and reacts on the diaphragm, forcing it to resume its original position. This action compresses the control spring and relieves the pressure against the seat holder, thus permitting the valve spring to force the seat against the nozzle and shut off the flow of gas. When the torch valves are opened, the pressure of gas against the diaphragm is reduced, and the pressure adjusting spring forces the diaphragm against the yoke or spacer pin, which in turn forces the seat away from the nozzle and permits the gas to flow through the regulator. The resultant balanced action maintains a constant volume and steady pressure of the gases at the adjustment set by the operator. The volume and pressure of the gases required for the size tip or nozzle being used are controlled by simply turning the adjusting screw to the right or clockwise to increase the pressure, and to the left or counterclockwise to decrease the pressure. The two-stage regulator (fig. 3) automatically reduces the initial cylinder pressure to approximately 200 pounds per square inch in the first stage of reduction by means of an additional diaphragm controlled valve incorporated in the regulator body. The final or last stage of pressure required at the torch is accomplished with the adjusting screw in the same manner as in the single-stage regulator. The two-stage reduction regulators are preferable for the regulation of oxygen pressure direct from the cylinders to the torch, as they permit more accurate adjustment and reduce the possibility of the flame change after the initial adjustment has been made.

6. **Welding torches.**—*a.* The welding torch is the unit used to mix the two gases together in correct proportions. It also provides a means of directing and controlling the size and quality of the flame produced.

b. Welding torches in general are divided into two classes: the balanced pressure type and low pressure or injector type. These torches are obtainable in different sizes and styles, thereby providing a suitable type for each of the various classes of work. They are also obtainable with several different sizes of interchangeable tips in order that a suitable amount of heat and size of flame can be obtained for welding the various kinds and thicknesses of metals.

(1) Figures 5 and 6 show two styles of balanced pressure torches. These units operate with each gas under a pressure of at least 1 pound per square inch. Equal pressures are used in some makes, while in others the pressure of the oxygen is held above that of the acetylene.

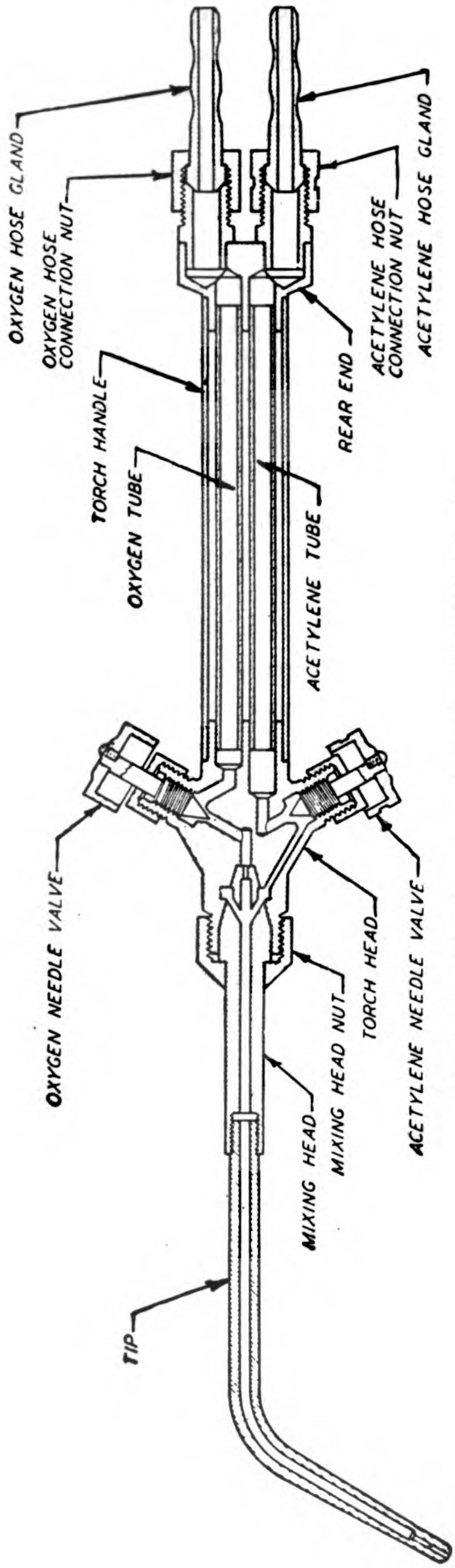


FIGURE 5.—Equal pressure type aircraft welding torch.

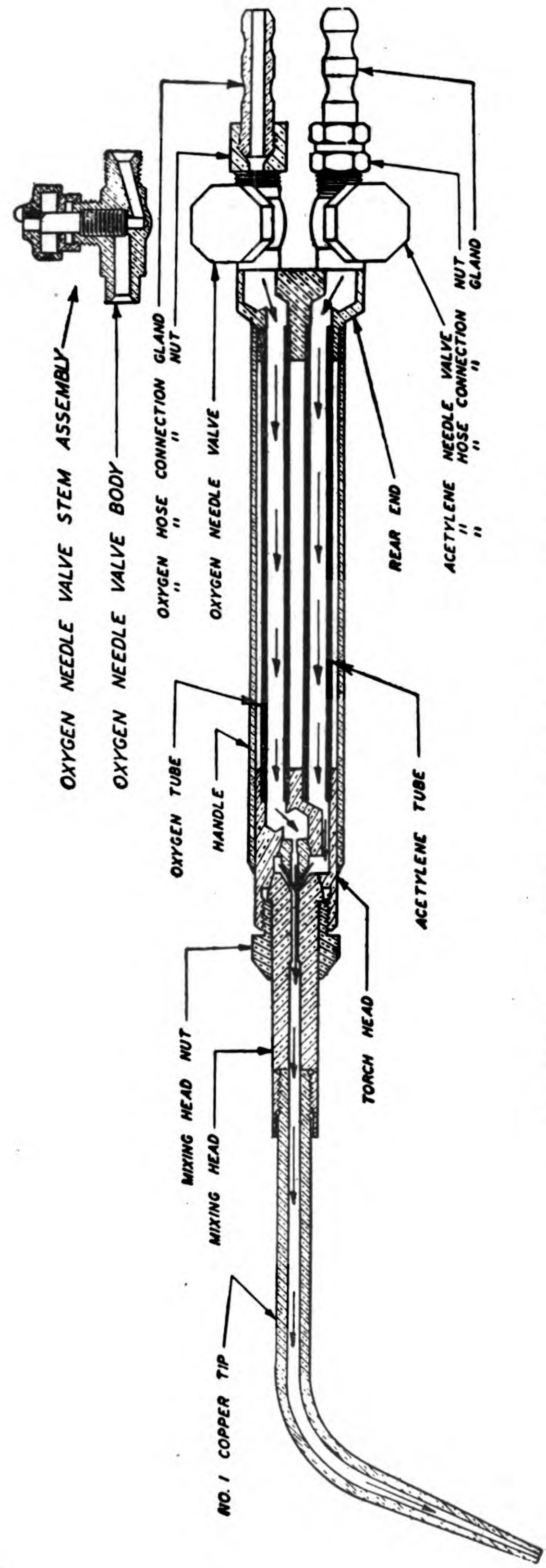


FIGURE 6.—Equal pressure type general purpose welding torch.

Regardless of type, the pressure of both gases must be increased for each increase in tip size.

(2) Figures 7 and 8 show the operating principles of low pressure acetylene, injector type torches. These torches are designed to operate with very low acetylene pressure as compared to that of the oxygen. The aircraft torch (fig. 7) operates at a uniform oxygen pressure of 20 pounds per square inch for all sizes of tips. The acetylene is under low pressure (not more than 1 pound per square inch) for all sizes of tips, as only enough pressure is required to overcome line friction until the acetylene reaches the injector nozzle through which the oxygen issues. The high velocity of the oxygen creates a vacuum effect that draws or sucks the required amount of acetylene into the mixing chamber (fig. 8) where the two gases are thoroughly mixed and passed on through the tip.

c. Some makes of torches are provided with an individual mixing head for each size of tip, while other makes have only one for several tip sizes. Nozzles are furnished in various styles or types, some having a one piece hard copper tip and others having a two piece tip which includes an extension tube to make connections between the tip and mixing head. Removable tips are made either of hard copper or a copper alloy, such as brass or bronze. The sizes of the tips are designated by numbers, each manufacturer having his own arrangement for classification. The tip sizes differ in the diameter of the orifice in order to obtain the correct volume of heat for the work to be done. Tables I and II give approximate gas pressure for the various tip sizes in general use.

TABLE I.—*Approximate pressure of acetylene and oxygen for the different size tips of an equal pressure type torch*

Size tip (orifice number)	Acetylene pressure	Oxygen pressure
	Pounds per square inch	
00	1	1
0	1	1
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6

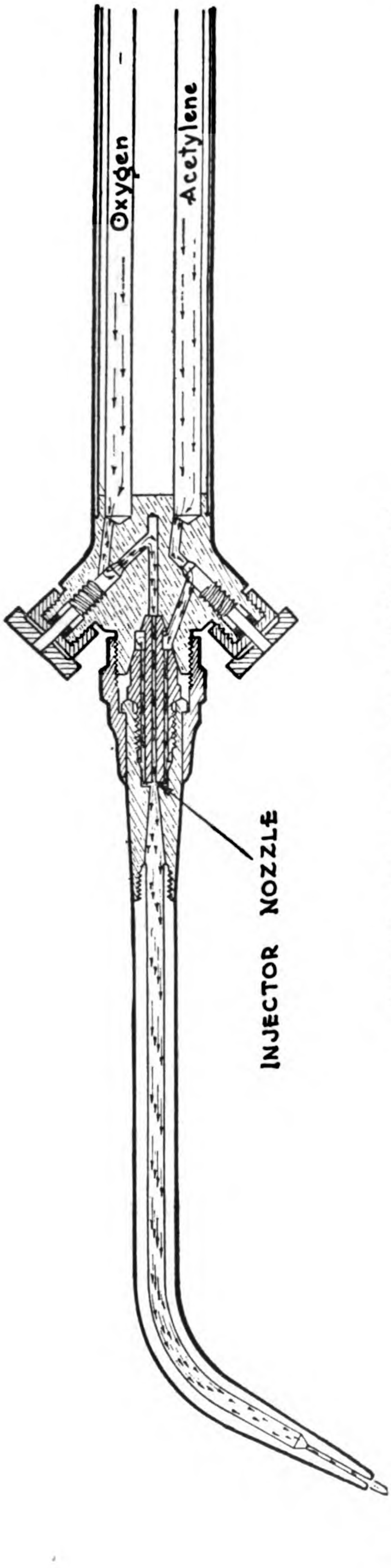


FIGURE 7.—Injector type aircraft welding torch.

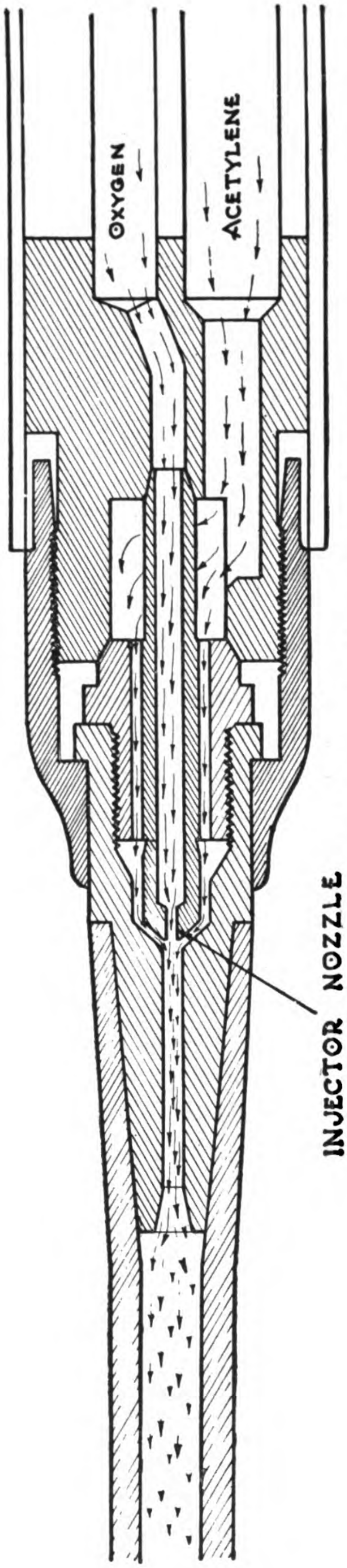


FIGURE 8.—Mixing head for the injector type welding torch.

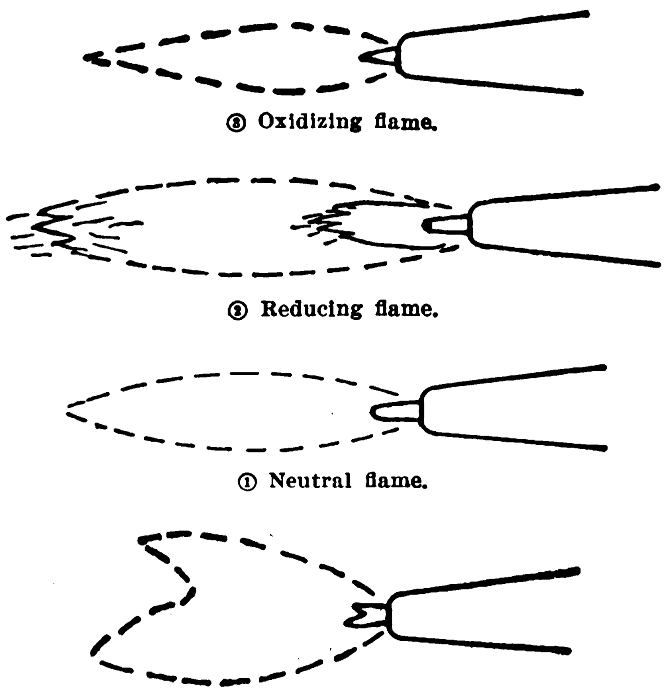
TABLE II.—*Pressure of acetylene and oxygen for the different size tips of an injector type torch*

Size tip (orifice number)	Acetylene pressure	Oxygen pressure
	Pounds per square inch	
0	1	9
1	1	9
2	1	10
3	1	10
4	1	11
5	1	12
6	1	14
7	1	16
8	1	19
10	1	21
12	1	25
15	1	30

7. Acetylene and oxygen welding hose.—The hose lines, which are used to make connections between the torch and regulators and to convey the gases from their containers to the torch, are especially manufactured for oxyacetylene welding and cutting. They are strong, nonporous, and as light as possible. The strength and size are dependent upon the class of work for which they are intended. For light aircraft welding torches, a light flexible hose which is capable of withstanding a hydrostatic pressure of 200 pounds per square inch is recommended, while for heavy duty welding and cutting, a hose which is capable of 400 pounds per square inch is required. The size of hose is designated by the inside diameter and number of plies of fabric. Those used for the light torches are ⅛ inch to $\frac{3}{16}$ inch inside diameter and have 1 or 2 plies of fabric. Those used for heavy duty torches and light cutting operations are ¼ inch to $\frac{5}{16}$ inch inside diameter and have 3 to 5 plies of fabric. The rubber used in the manufacture of welding hose is chemically treated to remove the sulfur in order to preclude any possibility of spontaneous combustion. The acetylene and oxygen hoses are the same in grade but different in color. Red or maroon is used for acetylene and black or green for oxygen. They are made up in lengths ranging from 12½ to 25 feet, as the length used depends upon the distance the welding apparatus is located from the work. The shorter lengths are preferable because additional pressure of the gas is required to overcome line friction in the long lengths. Long hoses also kink easily which restricts the flow of the gas and results in

fluctuating pressures. Hoses are equipped with connections in each end in order that they can be attached to their respective regulator outlet and torch inlet connections. These connections consist of a nut and tail piece. The nuts are the same size but have different threads, left hand being standard for acetylene connections and right hand for oxygen connections. The tail pieces are made in three standard sizes to fit hoses whose inside diameters are 3/16 inch, 1/4 inch, and 5/16 inch, respectively.

8. **Oxyacetylene flames.**—The characteristics of the different kinds of flames produced by burning acetylene gas with oxygen gas in various proportions are shown in figure 9.



③ Oxidizing flame.

② Reducing flame.

① Neutral flame.

④ Neutral or oxidizing flame produced by an obstructed tip.

FIGURE 9.—Oxyacetylene flame regulation.

a. The neutral flame (fig. 9①) produced by burning acetylene with oxygen in such proportions as to oxidize all particles of carbon and hydrogen in the fuel gas (acetylene), resulting in a flame temperature of approximately 6,300° F. This flame is distinguishable by the well-rounded, smooth, clearly defined central cone. This cone is white while the envelope or outer flame is blue with a purple tinge at the point and edges. Theoretically, 2½ volumes of oxygen are required to burn 1 volume of acetylene in order to produce the neutral flame, but it is only necessary to furnish 1 volume of oxygen through the torch for each volume of acetylene consumed, as the

remainder of the oxygen required is taken from the atmosphere. The carbon monoxide and hydrogen gas that issue from the first zone of combustion combine with oxygen from the air to complete combustion, forming carbon dioxide and water vapor.

b. The carbonizing or reducing flame is shown in figure 9②. As the oxygen furnished through the torch is not sufficient to complete combustion of the acetylene, carbon escapes unburned. This flame is recognized by the greenish white, brushlike second cone at the tip of the first cone. The outer flame is slightly luminous and has about the same appearance as an acetylene flame burning freely in air alone.

c. An oxidizing flame (fig. 9③) contains an excess of oxygen which is the result of too much oxygen passing through the torch. The oxygen not consumed in the flame escapes to combine with the metal. This flame is recognized by the short, pointed, bluish white central cone. The envelope or outer flame is also shorter and of a lighter blue color than the neutral flame. It is accompanied by a harsh sound similar to high pressure air escaping through a small nozzle. This flame oxidizes or burns most metals and should be avoided unless especially specified. The flame must be checked every few minutes to make sure it has not changed to the oxidizing side. To do this, slowly close the torch oxygen valve until a second cone or feathery edge appears at the end of the white central cone, then open the oxygen valve slightly until the second cone just disappears.

d. The flame (fig. 9④) is very unsatisfactory and should be corrected as soon as it appears. The irregular-shaped cone is due to an unclean tip and may cause considerable welding trouble.

9. Rules for handling and operating oxyacetylene welding apparatus.—*a. Assembling apparatus using cylinders of acetylene and oxygen gas.*—(1) Place cylinders in position with the acetylene valve outlet nipple directed away from the oxygen and secure each cylinder to prevent it from being pulled or knocked over.

(2) Remove valve protector caps and open valve of each cylinder (one at a time) for an instant only to blow out any dirt or dust collected in the outlet nipple.

(3) Attach regulators to their respective cylinder valve outlet nipples and tighten firmly with a close fitting wrench.

(4) Release each regulator adjusting screw to relieve any pressure on the diaphragm, turning screw counterclockwise to obtain this condition.

(5) Open cylinder valves slowly, oxygen fully open, and acetylene not more than one full turn. Leave key or wrench on the acetylene valve stem.

(6) Connect hose to their respective regulator outlet connections and tighten nuts firmly.

(7) Open regulators slightly and blow out hose; then release regulator screws.

(8) Connect hose to the torch (acetylene hose to connection with left hand thread and oxygen hose to connection with right hand thread).

(9) Select size tip to be used and firmly attach it to mixing head or extension tube.

(10) Open torch acetylene valve and turn acetylene regulator adjusting screw clockwise until the required acetylene pressure for the size tip being used is shown on the working pressure gage; then close torch acetylene valve.

(11) Open torch oxygen valve and turn oxygen regulator adjusting screw clockwise until the required oxygen pressure for the size tip being used is shown on the working pressure gage; then close torch oxygen valve.

(12) Open torch acetylene valve and light torch with the gas lighter; then adjust flow of gas with the torch valve until a slight gap exists between the end of the tip and flame.

(13) Open torch oxygen valve slowly until the central cone becomes smooth and well rounded.

b. Closing down welding apparatus.

(1) Close torch acetylene valve.

(2) Close torch oxygen valve.

(3) Close acetylene cylinder valve.

(4) Close oxygen cylinder valve.

(5) Open torch acetylene valve and drain acetylene hose and regulator.

(6) Turn acetylene regulator adjusting screw counterclockwise to relieve the pressure on the diaphragm and close torch acetylene valve.

(7) Open torch oxygen valve and drain oxygen hose and regulator.

(8) Turn oxygen regulator adjusting screw counterclockwise to relieve the pressure on the diaphragm; then close torch oxygen valve.

(9) Hang torch and hose up properly to prevent kinking of the hose or injury to the torch.

c. Testing apparatus for gas leaks.—After assembling the apparatus, all connections should be tested to insure against gas leaks. This is accomplished as follows:

(1) Open cylinder valves one turn.

(2) Adjust regulators so the gases will enter the hose lines, but keep torch valves closed.

(3) Close regulators and note if the working pressure gage shows a drop in pressure. If a pressure drop is noted, there is a leak in the hose line or connections, either at the torch or regulators. Leaking torch valves will also cause a pressure drop.

(4) Close cylinder valves and note if there is a pressure drop on the regulator tank pressure gage. If a pressure drop is noted at that point, there is a leak either in the connection between the cylinder valve and regulator connection or a defective regulator valve seat. A leak around the cylinder valve stem will also cause a pressure drop in the tank pressure gage.

(5) If there are indications of gas leaks by the test outlined, they can be located easily by turning on the gas pressure and applying a solution of soap and water to all connections. Where leaks exist a soap bubble will indicate their location. The hose lines may be tested for leaks by submerging them in water with the pressure on.

d. Rules.—The following rules are extremely important and should be carefully observed:

(1) Do not leave torch burning when not in use.

(2) Do not leave torch valves open when the torch is not burning.

(3) Do not operate with defective equipment.

(4) Do not permit flame to come in contact with any part of the welding equipment.

(5) Do not direct flame toward yourself or others.

(6) Do not stand in front of the cylinder outlet nipple when opening the cylinder valve.

(7) Do not permit oil or grease to come into contact with any part of the welding apparatus.

(8) Do not open cylinder valves before checking the regulators to see that the adjusting screw is fully released.

(9) Do not handle units of the welding apparatus carelessly; they are to be used for the purpose intended only and must not be altered or tampered with.

(10) Do not permit acetylene to come in contact with oxygen, other than in the torch.

10. Regulator troubles and remedies.—*a.* (1) The principal trouble experienced with regulators is leaking valves. This trouble is indicated either by the working pressure gage showing a gradual increase in pressure after adjustment, or by the building up of pressure when the adjusting screw is fully released. The term "creeping regulators" is usually applied to this defect, which is the result of worn or cracked valve seats, or foreign matter becoming lodged between the seat and nozzle. Regulators with leaking valves should be repaired immediately, otherwise damage to other parts of the regulator or apparatus will likely occur.

(2) When a leaking valve is indicated, the seat should be removed for inspection and if found to be worn or otherwise damaged it should be replaced with a new one. If the trouble is due to a fouled seat, the seat and nozzle should be thoroughly cleaned and any dust or dirt in the valve chamber blown out before reassembling. The procedure for removing the valve seats from regulators varies with the make or design. Some regulators are constructed so that the valve seat is accessible by removing a threaded cap from the valve chamber and a seat retaining screw in the seat holder. A vise and screw driver are the only tools needed in this case, while other makes require dismantling the spring case and diaphragm, sometimes requiring special tools.

b. (1) Broken or buckled gage tubes and distorted or buckled diaphragms are other regulator troubles to be considered. These defects are usually due to a backfire at the torch, leaking regulator valves, or failure to release the regulator adjusting screw fully before opening the cylinder valves. Defective gage tubes are indicated by improper action and gas escaping from the gage case. Pressure gages with defective tubes should only be repaired in the ordinary welding shop in the case of extreme emergency as special equipment is required to obtain satisfactory results. When defective tubes are discovered, the gage should be removed and replaced with a new one, making sure that it is the correct type and that a gas-tight fit is obtained.

(2) Buckled or distorted diaphragms will not respond properly to adjustment and should be replaced with new ones. Metal diaphragms are sometimes soldered to the valve case, and replacement requires complete dismantling of the regulator so that the soldering heat will not affect other working parts. This is a factory or special repair shop

job and should not be attempted by any workman who is not familiar with the work. Rubber diaphragms can easily be replaced by removing the spring case, a vise or wrench being the only tool needed.

11. Welding torch troubles and remedies.—*a.* All torch troubles should be determined and corrected immediately or the torch taken out of service until the necessary repairs can be made.

b. The troubles that contribute to improper functioning of welding torches consist of leaking valves, leaks in the mixing head seat, scored or out of round tip orifices, and clogged tubes and tips.

(1) *Leaking valves.*—Leaking valves are indicated when the gases continue to flow after the valves are closed. This condition is due to worn valve needles, damaged seats, or a combination of both. In case the valve needle only is worn, the trouble can be remedied by replacing this part with a new one. If the seat is worn or otherwise damaged, it will be necessary to reface it in order to correct the trouble.

(2) *Leaking mixing head seats.*—Leaks existing between the oxygen and acetylene inlet orifices which lead to the mixing head will cause improper mixing of the gases and result in flashbacks (igniting and burning of the gases back of the mixing head in the torch tubes). This trouble is indicated by the flame popping out and sparks being emitted from the tip. A flashback will cause the torch head and handle tube suddenly to become excessively hot. Troubles of this nature can only be remedied by reaming the seat in the torch head and truing up the seat of the mixing head.

(3) *Tip orifices.*—Scored or out-of-round tip orifices will be indicated when the proper shape flame cannot be obtained after having thoroughly cleaned the tip. This condition can only be corrected by replacing the tip with a new one.

(4) *Clogged tubes and tips.*—(*a*) Clogged torch tubes and tips are indicated when greater pressure of the gases is necessary to produce the flame than is normally required for the size tip being used. With this trouble the flame will become distorted, having characteristics similar to the flame shown in figure 9④. The condition is due to carbon deposits caused by back fires and flashbacks or the presence of foreign matter which has entered the torch through the hoses. To remedy the trouble, the torch should be disconnected from the hose and each hose blown out with its gas to remove any loose particles of foreign matter in it. The tip should be removed and thoroughly cleaned with a soft copper or brass wire, then blown out with oxygen. The mixing head may be removed and cleaned in the same way as suggested for the tip, although care must be used to prevent

enlarging the orifice through which the gases enter the head. The oxygen hose should next be inserted into the torch head and the tubes blown out using a pressure of from 20 to 30 pounds per square inch.

(*b*) Torches which have worn valve seats or mixing head seats should be sent to the manufacturer for repairs, as these conditions require a special reamer which is not available in the average shop.

12. Acetylene cylinders.—*a*. The cylinders used to store acetylene under pressure vary to some extent in size and appearance, as each manufacturer uses a slightly different shape as well as a different kind of filler. However, all are constructed to comply with the specifications of the Interstate Commerce Commission and Bureau of

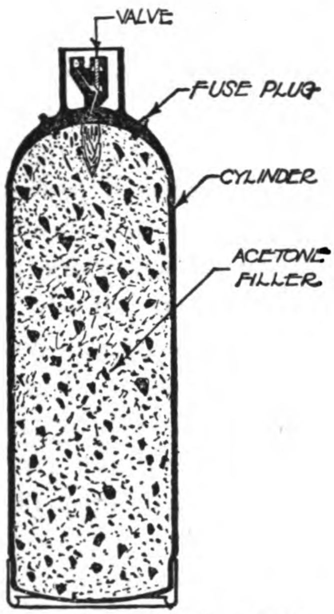


FIGURE 10.—Cross section of an acetylene cylinder showing acetone filler.

Explosives. Those used to supply acetylene for welding purposes have gas capacities of 110, 250, 275, and 300 cubic feet.

b. The shells are of seamless steel construction and are filled with a substance having a porosity of 75 to 80 percent. They are all provided with a valve, safety plugs, and some means of protection for the valve when the cylinder is in storage or transit. (See fig. 10.) The purpose of the filler is to distribute the acetone. The material is such that it absorbs acetone in the same manner as a sponge absorbs water, and when this filler is thoroughly saturated, there is no space in the cylinder for acetylene to free itself of the liquid until the cylinder valve is opened. The amount of acetone required for the various sizes of cylinders is 40 percent by volume of the fluid capacity.

c. The acetylene cylinder valves are made of a high strength copper alloy (brass or bronze) and have male or female outlet connections for

attaching to the regulator or manifold. The majority of these valves have a male outlet connection and are threaded with ½-inch straight pipe thread (14 threads per inch). The valve stem terminates in an end that requires a key or wrench. The type of valve that is provided with a female outlet connection is threaded with a left-hand thread and requires an adapter for use with equipment designed for the other type valve.

d. The safety plugs for acetylene cylinders are made of steel and have a small hole through the center which is filled with a low melting point metal alloy. They are threaded and screwed into the top of the cylinder on each side of the valve and in some cylinders two or three are set in the bottom. The metal alloy in these plugs melts at a temperature of 212° to 220° F. In case the cylinder is overheated, this alloy will be forced out and will permit the gas to escape through the small openings in the plugs before a dangerous pressure is built up in the cylinder. The holes in the plugs are small enough to cause the gas to escape at a speed that will prevent the flame burning back into the cylinder in case the escaping gas is ignited.

e. The charging capacity of acetylene cylinders, as set forth by the Bureau of Explosives, is 250 pounds per square inch at a temperature of 70° F. The volume of gas contained in the cylinder at this pressure depends upon the size. The cubic feet of acetylene in a cylinder may be calculated by weighing the cylinder and subtracting the tare weight stamped on the cylinder from this gross weight. The difference in pounds is then multiplied by 14.5, which gives the number of cubic feet.

13. Oxygen cylinders.—*a.* The standard cylinder used to store and transport oxygen gas for welding and cutting purposes is a seamless steel bottle-shaped container and is made to withstand exceedingly high pressures. The initial charging pressure at the plant is 2,000 pounds per square inch at a temperature of 70° F. Two sizes are in general use: a small cylinder having a capacity of 110 cubic feet of oxygen, and the standard size cylinder having a capacity of 220 cubic feet. They are provided with a special valve and a metal cup-shaped cap for protection of the valve when in storage or in transit. A threaded metal ring is shrunk on the neck of the cylinder for attaching the valve cap.

b. Figure 11 shows the construction of an oxygen cylinder and oxygen cylinder valve assembly. The valve shown is the needle type and is made of a high strength noncorrosive copper alloy having a tapered pipe thread on the end that screws into the cylinder. The outlet nipple is 29/32 inch in diameter and is threaded with a straight

pipe thread (14 threads per inch). A bursting disk is contained in the nipple at the rear of the valve and consists of a thin copper diaphragm supported by a fusible alloy metal washer, held in place over the end of the nipple with a cup-shaped nut. The alloy washer melts at approximately 240° F., and in case the cylinder is exposed to a temperature above this point, the disk will burst and release the pressure before the expanding gas can reach a dangerous pressure in the cylinder. The valve stem is made in two parts, and the two sections are connected by means of a slide joint which permits the lower section

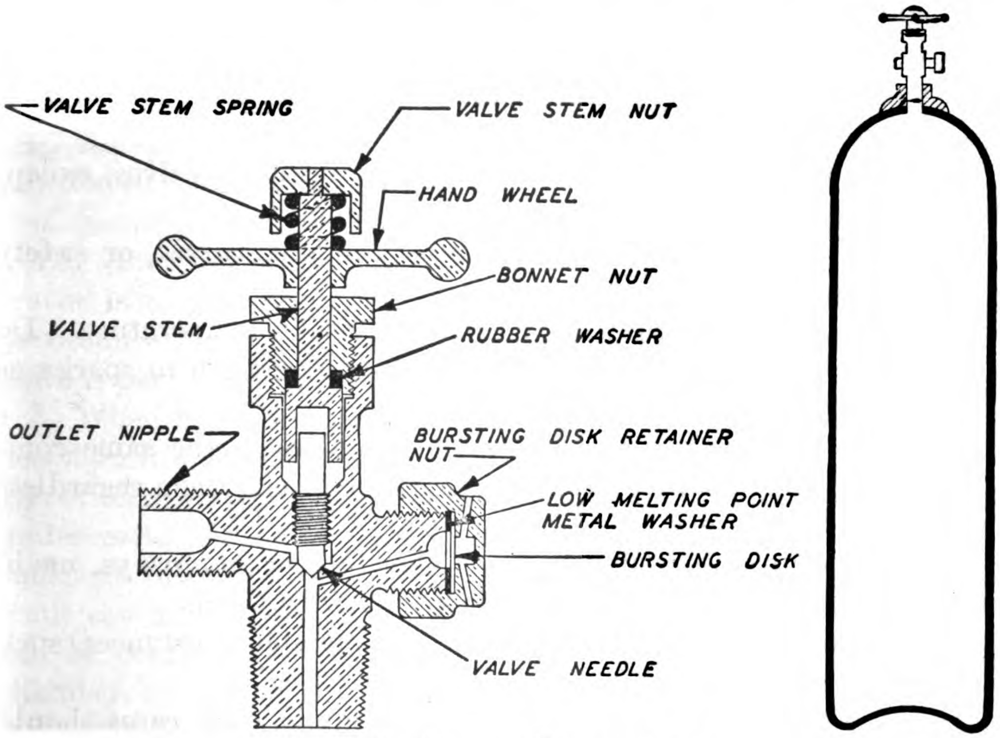


FIGURE 11.—Oxygen cylinder and valve.

to move up and down in opening and closing the valve. The lower section is threaded and contains the valve seat needle which is made of Monel metal. The handwheel used in opening and closing the valve is connected to the upper section of the stem. The rubber compression disk around the valve stem, which is held in place with the bonnet nut, provides a gas-tight seal. When the valve is completely open, the lower section exerts pressure against the upper section of the stem and compresses the rubber disk giving added protection against leakage.

14. Rules for handling and storage of acetylene and oxygen cylinders.—The following are general rules relative to the handling of acetylene and oxygen cylinders:

a. Never drop cylinders or permit them to be struck violently.

b. Do not use a lifting magnet or a sling to lift cylinders. If a crane is used, a safe cradle or platform must be provided to hold them.

c. Secure cylinders while in use to prevent their being knocked or pulled over.

d. Before connecting the cylinders, open valve for an instant to blow out dust or dirt from the outlet nipple, being sure to point the valve opening away from you.

e. Avoid blowing dangerous amounts of combustible gases in confined places.

f. Do not use wrenches or other tools for opening valves, except those provided or approved by the gas manufacturer.

g. Do not attempt to alter or repair cylinders, valves, or safety devices.

h. Protect cylinders against any excessive rise in temperature. Do not place them near furnaces, radiators, or expose them to sparks or open flames.

i. Do not store oxygen and acetylene cylinders in the same compartment. There should be a fireproof wall between them regardless of whether full or empty.

j. Do not store full cylinders near elevators or gangways, or in runways where moving objects may strike or fall on them.

k. Never store cylinders near highly inflammable substances, such as oil, gasoline, waste, etc.

l. Cylinders may be stored in the open, but in such cases should be protected against extremes of weather. During winter, cylinders stored in the open should be protected against accumulation of ice and snow. In summer, they should be protected against continuous, direct sun rays.

m. Store full and empty cylinders apart and mark the latter "M. T."

n. Cylinders should be used in the order received to avoid rental charge.

o. Close valves when empty and see that the valve protection caps are in place before shipping.

p. Never use cylinders for rollers, supports, or any purpose other than gas containers for which they are intended.

q. Do not open acetylene cylinder valve more than one turn.

r. Fully open oxygen cylinder valve when the cylinder is in use.

s. Do not discharge an acetylene cylinder in less than 5 hours or one-fifth its capacity per hour.

t. Acetylene cylinders should be stored and used in an upright position when possible. In case it is necessary to lay the cylinder down when in use, the top should be elevated as much as possible with the outlet nipple pointing upward.

u. Do not attempt to transfer acetylene from one cylinder to another or fill the cylinder except with the consent of the owner, and then only in accordance with the Interstate Commerce Commission regulations.

v. Never use acetylene or oxygen from cylinders without proper regulators to reduce and control the gas flow.

w. Keep all connections to the cylinder gas-tight to prevent leakage.

x. Never test for gas leaks with an open flame or oil. Use a solution of soap and water.

y. Never use oxygen as a substitute for compressed air.

15. **Acetylene generators.**—*a.* The function of an acetylene generator is to bring calcium carbide and water into contact in order to produce clean, cool acetylene under a pressure not exceeding 15 pounds per square inch.

b. When calcium carbide and water are brought into contact, the decomposition of the carbide results in excessive heat being liberated. Experiments have shown that the reaction between carbide and water, under certain conditions, will reach an incandescent heat which is sufficient to ignite an explosive mixture of acetylene. No arrangement can alter the amount of heat liberated by this reaction, but it can be controlled by having an excess of water in the generating chamber, as compared to the amount of carbide in contact with water at one time. The excess water absorbs the heat as it is liberated, thus preventing the danger of overheating. The National Board of Fire Underwriters' specifications require all generators which are used to produce acetylene in large quantities (such as for welding systems and large lighting systems) to have 1 gallon of water for each pound of carbide capacity of the generator.

c. There are three types of generators used to produce acetylene: carbide-to-water, water-to-carbide, and recession types. With but few exceptions, the carbide-to-water generator is used to manufacture acetylene for welding systems. The water-to-carbide type is used for small lighting systems, such as miner's lamps, bicycle lamps, etc. The recession type generators are principally used to produce acetylene in comparatively small quantities, such as is used with portable welding outfits and lighting systems.

(1) The water-to-carbide generators operate by allowing water to drip on an excess of carbide contained in the generating chamber. This method of bringing carbide and water together has the undesirable feature of "after generation" and overheating. When it is desired to stop the system and the water is turned off, generation will continue until the carbide has absorbed all the moisture in contact with it, thereby continuing to generate additional gas. This is a dangerous feature because it is impossible to stop generation when desired and, also, the generator is liable to become excessively hot.

(2) In the recession type generator, carbide, which is contained in a basket and attached to a gas bell, is either lowered to the water or held stationary and the water level raised to it. Figure 12 shows the construction and operating principles of a recession generator known as the carbic low pressure type. There are no moving parts in this type of generator, and the carbide is processed and compressed into cylindrical cakes. These cakes rest, one on top of the other, in the holder. When the gas valve is opened, the water rises in the gas bell and comes in contact with the bottom of the lower cake of carbide until sufficient gas is generated to force the water down and away from the cake. This action is repeated during the operation of the generator. As the bottom cake of carbide is consumed, the one above it takes its place to keep the generation constant. A filter and water seal is located in the top of the gas bell to remove the solid particles and purify the gas before it passes out to the torch. This generator operates at a constant pressure of less than 1 pound per square inch. It can only be used with the low pressure injector type torch unless the pressure is boosted in some manner.

(3) The carbide-to-water type generators operate by slowly dropping carbide into an excess of water and are available for both low and medium pressures. The low pressure type operates at a pressure of less than 1 pound per square inch and can only be used with a low pressure injector type torch unless the pressure in the line is boosted. The medium pressure generator operates at a pressure of from 1 to 15 pounds per square inch. It is more widely used because any type of torch may be operated from it when a suitable regulator is used to control the flow of gas. The medium pressure type is made in several different sizes, ranging from 25 to 300 pounds carbide capacity. Various methods are used to operate the carbide feed mechanism, such as clock motors operated by springs, falling weights, or diaphragms operated by the pressure of gas generated. The carbide used for the different types of generators that drop the material into water ranges from the finely divided No. 14 screen size to the ⅜ by

1¼ inch lump. Figure 13 shows the construction and operating principle of diaphragm feed controlled generator. This unit is composed of the carbide hopper, water chamber, and flashback arrestor. The carbide hopper consists of a pyrex glass cylinder enclosed in a

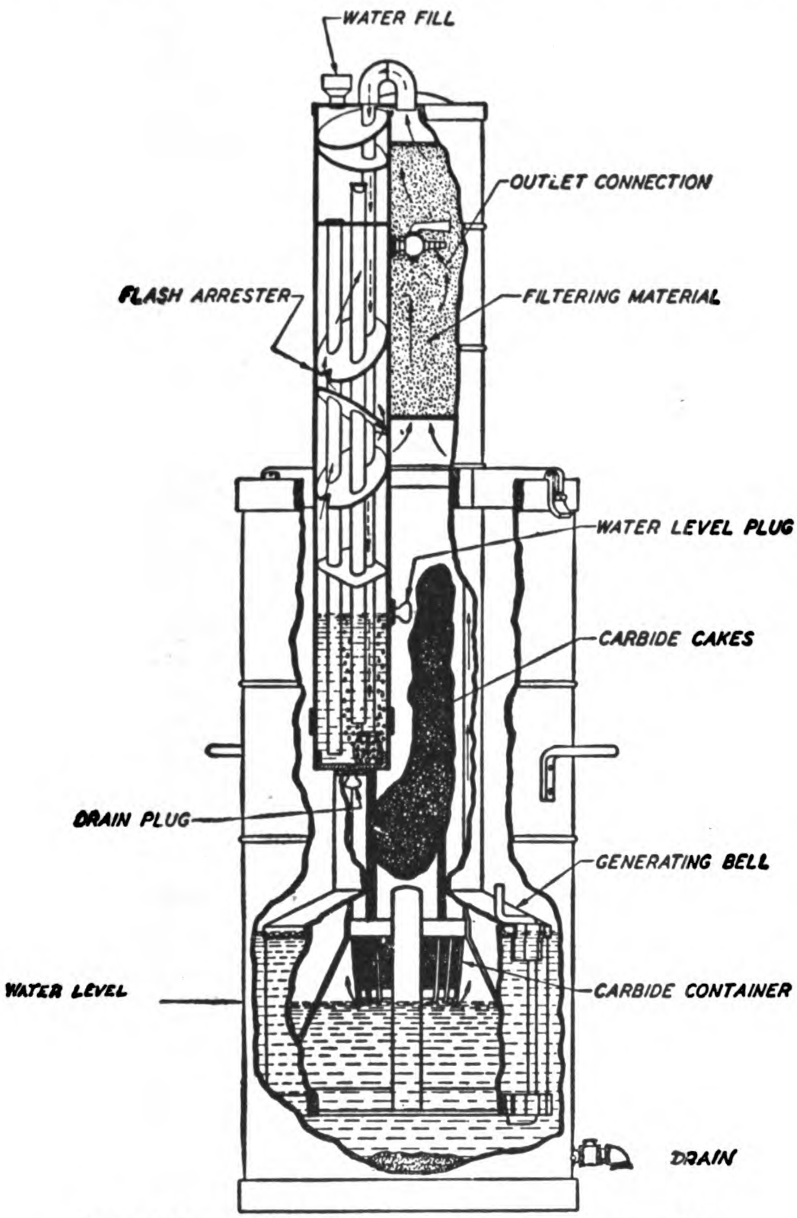


FIGURE 12.—Recession type portable acetylene generator.

metal screen. The diaphragm and feed control mechanism is located in the top of the hopper. This consists of a rubber diaphragm, pressure adjusting screw, compression spring, and locking lever. The feed rod is connected to the diaphragm and control mechanism by means of a flexible joint. When the locking lever is lifted to the

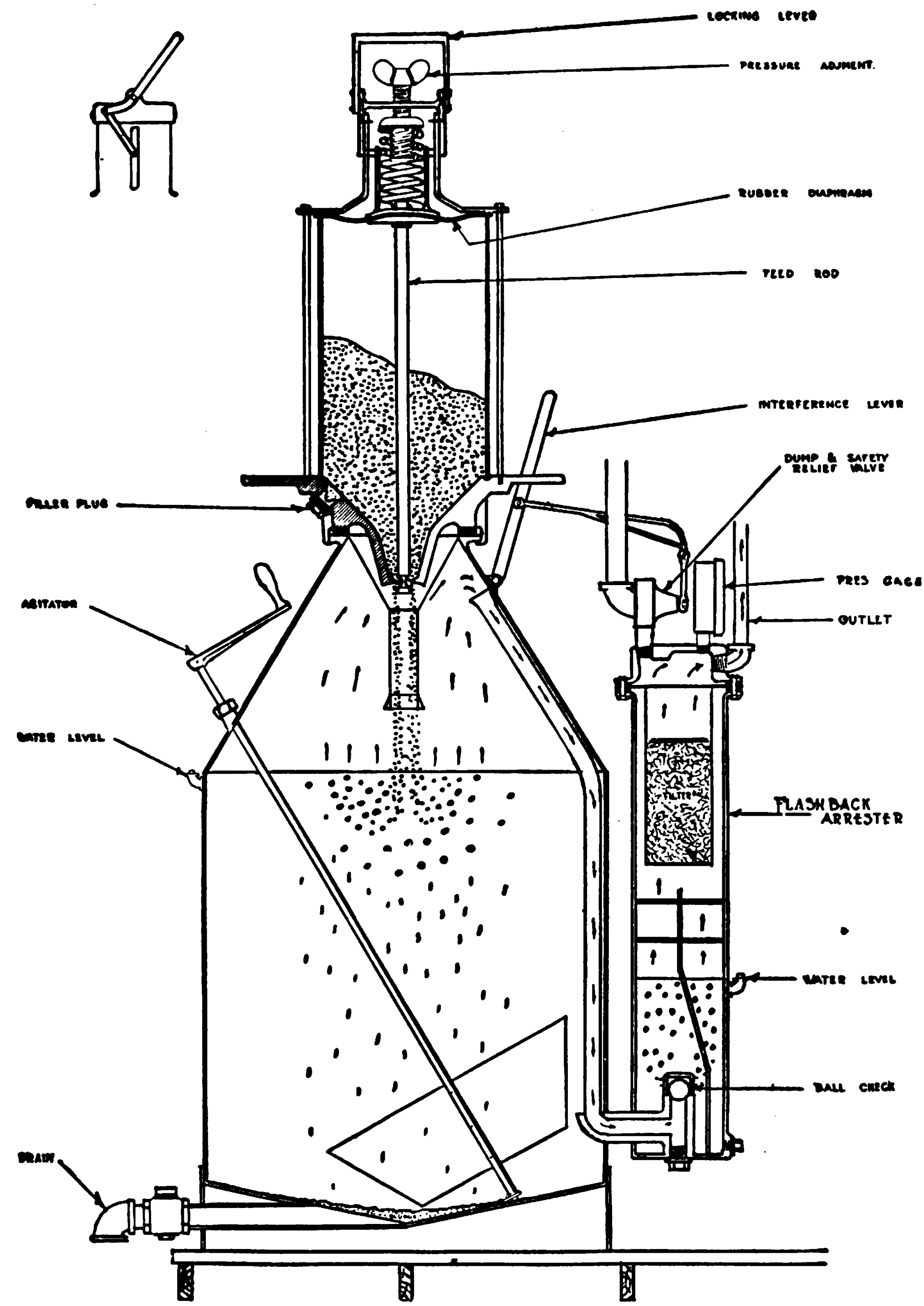


FIGURE 13.—Pressure type carbide-to-water acetylene generator.

feed position, the feed rod is forced down by the pressure of the spring against the diaphragm, thus opening the feed valve and allowing carbide to drop into the water in the generating chamber. The gas generated passes up through the carbide hopper and when the pressure on the diaphragm becomes great enough to overcome the spring pressure, the feed rod is raised, closing the feed valve and stopping the flow of carbide. When the gas pressure on the diaphragm drops, the spring forces the feed rod down, allowing carbide to flow again, and generation is resumed. This action is repeated as the gas is drawn from the generator. The adjusting screw is used to increase or decrease the pressure of gas required by varying the tension on the spring.

16. **Rules for safe operation of acetylene generators.**—Most manufacturers furnish instructions for the operation and care of their respective generators. There are, however, certain rules that apply to all makes and types that should be observed in order to avoid trouble.

a. Stationary generators should preferably be housed in a well-ventilated building detached from other buildings and heated with steam or hot water to prevent freezing temperatures. If the generator must be housed in a building with other equipment, a room with fireproof and gas-tight walls which is properly ventilated to the outside should be provided.

b. If artificial lights are used, all wires should be run in conduit and vaporproof bulbs provided. The light switch must be located on the outside of the building.

c. When charging, care must be taken to keep as much air as possible from entering the generating chamber, as a mixture of acetylene and air is highly explosive. To do this, no two operations of charging should be performed at one time. It is impossible to prevent some air from entering as it is being charged, and the first gas generated after charging should be allowed to escape through the vent pipe, carrying this air with it. It is not good practice to force the mixture through the service line, as a mixture of acetylene and air is liable to cause a flashback when the torch is lighted.

d. Before recharging a generator, it should first be drained and the slacked lime thoroughly rinsed out. The container may then be filled to capacity with fresh water.

e. When charging the generator from a carbide can, care must be taken that the can or other metal does not come in contact with the edge of the filling hole, as this contact is apt to produce a spark and cause an explosion.

f. The hydraulic reverse flow valve, or water seal chamber, should be inspected to see that it has the proper water level, and all relief valves should be frequently checked to insure that they work freely and do not leak.

g. In case the generator becomes hot from operation, the feed mechanism should be stopped immediately and the generator allowed to cool down before investigating the cause of the trouble. In general, this would be due to an insufficient amount of water, which may result from a faulty drain valve. It is very important to see that the water level is correct in all cases. After the generator has cooled to normal temperature, the cause of the increase in temperature should be determined and the necessary corrections made before starting again.

h. The volume of gas that may be generated in a given length of time without the danger of overheating is 1 cubic foot of gas per hour, per pound of carbide capacity. Therefore, a 50-pound carbide capacity generator will generate 50 cubic feet per hour, etc.

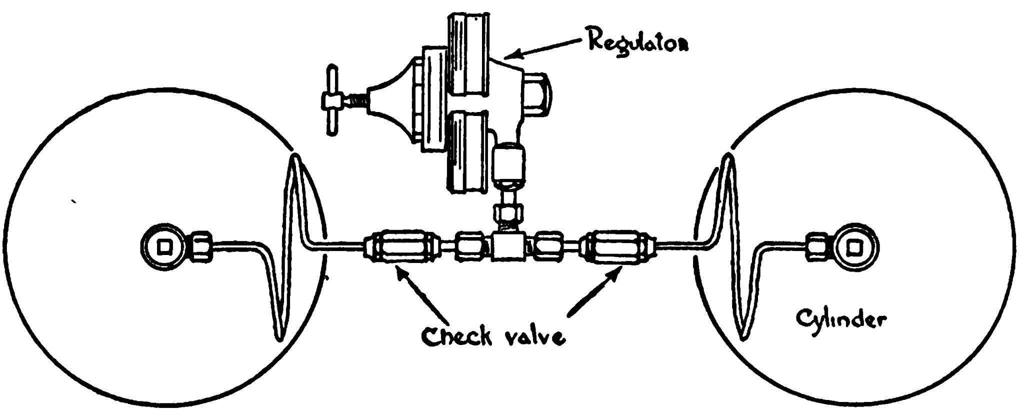
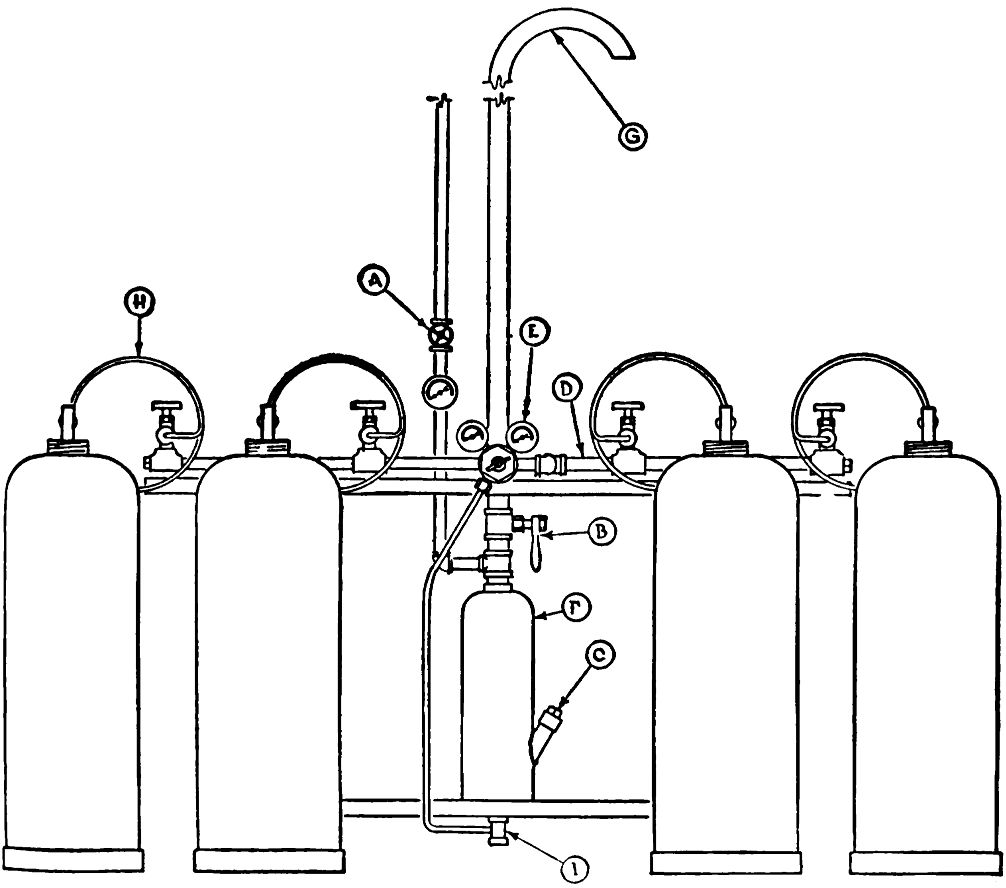


FIGURE 14.—Portable acetylene cylinder manifold.

17. Acetylene and oxygen manifolds and pipe lines.—*a*. When the volume of acetylene or oxygen required for large welding, cutting, or heating operations is excessive, two or more cylinders are connected to an approved manifold and the valves of each cylinder regulated to furnish an equal volume of the gas. A master regulator must be attached to the header of the manifold, for regulating the flow and pressure of gas to the torch or distributing pipe lines.

b. These manifolds are constructed of material amply strong to withstand the pressure of gas to which the cylinders are charged when full, as well as to resist any chemical action of the gases. A portable manifold is used for field welding or cutting jobs where the gas required exceeds that which can be furnished by one cylinder, while a stationary type is usually used where installed in shops or schools where a number of torches are to be fed.

(1) *Acetylene cylinder manifolds.*—The piping or tubing used in the construction of acetylene manifolds is made of steel although the fittings and valves are of brass or bronze. A portable unit is shown in figure 14 and consists of a header block to which the regulator and cylinder branch pipes are connected. A reverse flow valve is connected in the lines in order to prevent a flashback in the torch from traveling to the cylinders. A stationary set-up is often used in shops



A. Line valve.
B. Release valve.
C. Filler plug.
D. Header pipe.
E. Regulator.
F. Flash arrestor chamber.
G. Escape pipe.
H. Cylinder connection pipe.
I. Check valve and drain plug.

FIGURE 15.—Stationary type acetylene cylinder manifold.

and establishments where the installation of an acetylene generator is not permissible and figure 15 shows the design of a four cylinder unit. It consists of a header (D), hydraulic flash arrestor (F), safety release valve (B), escape pipe (G), regulator (E), and cylinder connecting pipes (H). The header is equipped with a shut-off valve for each cylinder. The regulator is attached to the header pipe and to the flash arrestor through a steel tube to the check valve (I) at

the bottom. The safety release valve (B) is attached to the top of the flash arrestor in order to relieve the pressure of the gas in case it exceeds the safe working limit. The escape pipe (G) is connected to this valve and provides a means of exhausting escaping gas to the atmosphere. This vent should be standard $1\frac{1}{2}$-inch iron or steel pipe, terminating in a goose neck bend at the exhaust end. This end must not be less than 12 feet from the ground. Acetylene manifolds should be securely bolted to a level floor, preferably in a room with fireproof walls and ceiling. If this is not possible, it must be located at a safe distance from the operations of welding or cutting. Before placing a manifold of this type in service, the filler plug (C) should be removed and the flash arrestor filled with water until it overflows. The flash arrestor should be checked for deficient water at least twice a week and more often when heavy consumption of gas is involved. The check valve (I) which is located between the regulator and flash arrestor should also be checked once a week to see that it is operating properly. When the manifold is not in use for extended periods, the service line, cylinder, and cut-off valves should all be closed, the regulator adjusting screw released, and the relief valve opened.

(2) *Oxygen cylinder manifolds.*—The portable oxygen cylinder manifold is similar to the portable acetylene cylinder manifold, although the reverse flow valves are omitted. Stationary manifolds are obtainable in single and double rows, having capacities of 6 to 40 cylinders. The double row types are equipped with two regulators, in order that either bank of cylinders may be used independently of the other, and a set-up of this kind is shown in figure 16. A shut-off valve is provided for each section of the header bar in order that the regulators may be removed without closing the cylinder valves. The installation of oxygen cylinder manifolds should be made in a separate room from acetylene manifolds. The system should be equipped with a master shut-off valve conveniently installed between the manifold and the main distributing line. Permanent installations should be lined up and secured to the floor or wall with bolts or lag screws. When the manifold is not to be used for periods of several hours, the service line, header line shut-off, and cylinder valves should be closed and the regulator adjusting screw released.

(3) *Acetylene distributing pipe lines.*—The distributing pipe lines for acetylene gas are constructed of standard black wrought iron or steel pipe. They are equipped with safety devices at each end of the line to relieve excess pressure due to a flashback through the torch and regulators in the line. These safety devices are disks which

are designed to break at a pressure of 50 pounds per square inch. A vent pipe is connected to each bursting disk and led to the outside atmosphere. These vent pipes must conform to the same requirements as described for the acetylene cylinder manifold. A hydraulic flash arrestor is installed in the feeder line near the intake end of the distributor. This flash arrestor is equipped with a safety relief valve, which is also vented to the outside. Distributing lines are installed with the end opposite the intake elevated 1/8 inch for each

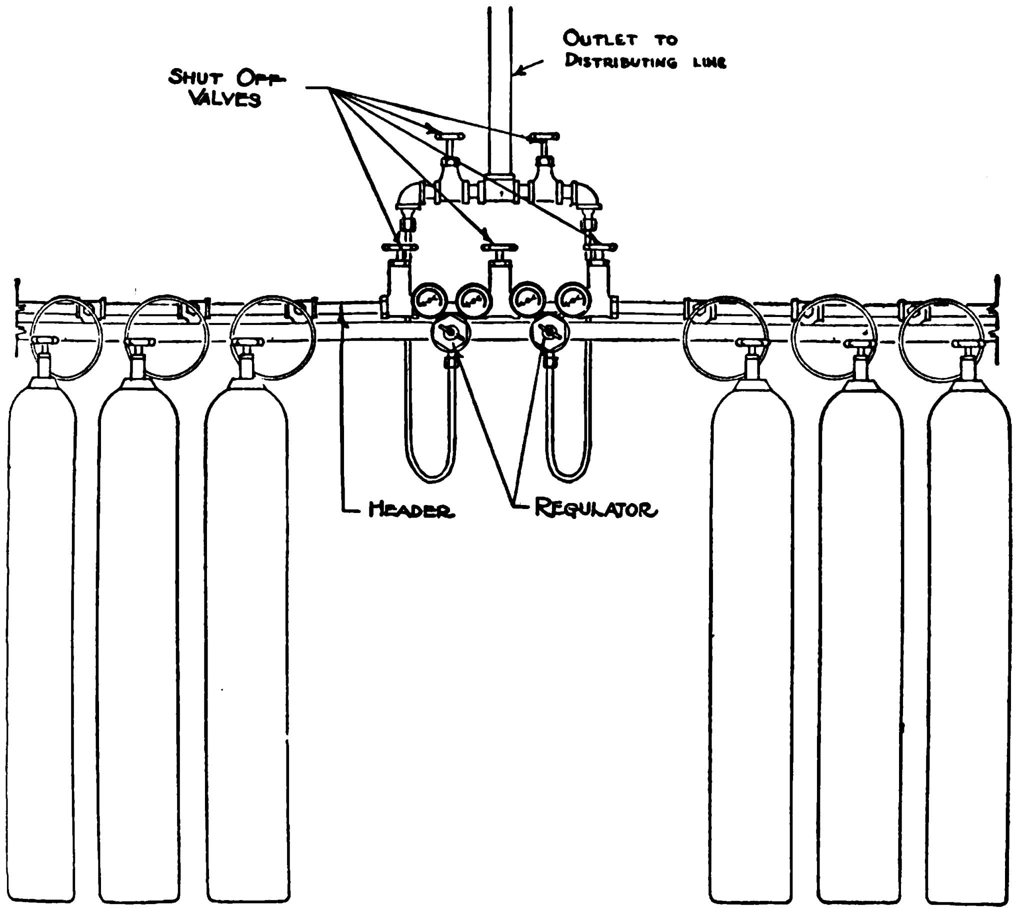


Figure 16.—Stationary type oxygen cylinder manifold.

foot of line length, in order that all condensation will drain back to the flash arrestor or a suitable moisture trap at the intake end. The welding station outlet for overhead lines should end in a loop (fig. 17). Welded joints are generally used for all acetylene pipe lines and connections, although threaded connections may be made. In the case of threaded joints, the connection must be sealed with a compound of glycerine and litharge. This mixture should be made up in small quantities and used before it begins to set.

(4) *Oxygen distributing pipe lines.*—Oxygen distributing pipe lines are installed in much the same manner as acetylene lines except that they do not require bursting disks or flash arrestor safety devices. They are installed so that they follow, and are parallel to, the acetylene line. Welded or threaded joints may be used and all threaded connections must be free from oil and sealed with glycerine and litharge.

18. Cleaning and testing acetylene and oxygen pipe lines.—When an installation of these lines is made, they should be thoroughly cleaned on the inside and tested for leaks before being used.

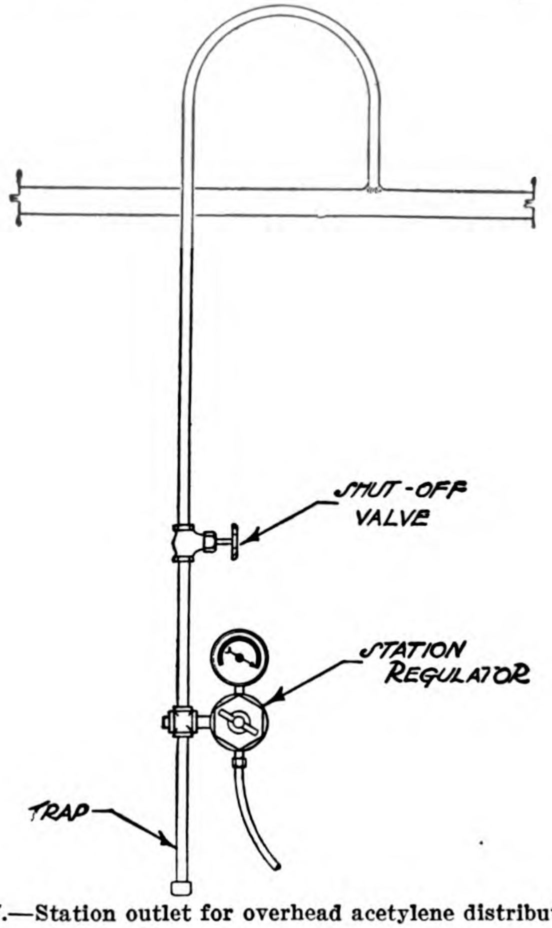


FIGURE 17.—Station outlet for overhead acetylene distributing line.

a. Cleaning.—Before installation, all piping must be freed of all scale or impurities that might react with either of the gases to cause combustion or corrosion. They may be blown out with live steam or washed with either carbon tetrachloride or a hot solution of caustic soda and water. The caustic soda solution is made by mixing 1 pound of soda to 1 gallon of water. All welded joints must be hammered to loosen the scale and then blown out by means of dry compressed air or steam.

b. Testing.—The method used in testing acetylene lines for ordinary working pressure is by the use of clean, dry compressed air or nitrogen. The testing medium is admitted in the line at a pressure of 40 pounds per square inch and allowed to flow until the delivery pressure is indicated at the end of the section under test. Oxygen lines are tested in the same way but at a gage pressure equal to 1½ times the maximum operating pressure. Painting the joints with a soap and water solution will indicate the location of leaks by the formation of bubbles. When air has been used in testing acetylene lines, the line should be purged by passing carbon dioxide gas through it.

SECTION II

WELDING FUNDAMENTALS

19. Welding terms.—The terms commonly used in the description of the various welding operations may be defined as follows:

Acetylene.—A highly combustible gas, composed of carbon and hydrogen (C_2H_2) and used as the fuel gas in oxyacetylene blowpipe welding.

Adhesion.—A condition existing in a welded joint where molten metal merely sticks to the adjacent metal without actually being fused with it.

Alinement.—The arrangement of parts in a straight line or proper position in relation to each other.

Alloy.—A combination of two or more different metals.

Asbestos.—A fibrous material refractory to heat, used in welding as insulation against transmission of heat from one body of metal to another.

Autogenous welding.—The process of joining two or more pieces of metal by fusing, without additional metal being added, and without the aid of hammering or pressure.

Backfire.—The popping out of the torch flame or momentary burning of gases in the torch head.

Backhand welding.—A method of welding with a blowpipe flame in which the flame is directed toward the finished weld.

Base metal.—The material composing the metal being welded.

Beveling.—The cutting or forming of angles on the edges or ends of metal shapes.

Blowhole.—A hole or cavity formed in the weld by trapped gases escaping from the hot metal as it solidifies.

Brazing.—The uniting of metal parts with metal having a lower melting point than the base metal.

Buckling.—Distortion of sheet or plate, due to the forces of expansion and contraction, by the application of heat or excessive loading.

Butt weld.—A weld made between the ends or edges of two pieces of metal.

Cold shut.—Poor fusion between the layers of weld metal or between the weld metal and base metal.

Contraction.—The shrinkage of metals due to cooling from an elevated temperature.

Conductivity.—The rate at which a metal will transmit heat through its mass.

Ductility.—The property which permits a metal to be drawn or formed into different shapes.

Edge weld.—The joining of two or more parallel pieces of metal by welding their edges together.

Elastic limit.—The maximum load that a metal will sustain before it takes on a permanent set.

Elasticity.—The property which, after distortion of the metal within certain limits, will cause the metal to resume its original form.

Elongation.—The deformation or total stretch of a metal caused by a tensile force.

Expansion coefficient.—The amount which a metal increases in length, per unit of length, per degree rise in temperature.

Filler rod.—A rod or wire used to supply additional metal to a weld.

Fillet weld.—A weld made in a corner such as required in a lap or tee joint.

Flame propagation.—The rate at which a flame travels or spreads through an inflammable substance.

Flashback.—The burning back of the gas through the torch. In some cases flashback may extend through the hose and regulator to the gas supply.

Flux.—A substance used to dissolve oxides, clean the metal, and prevent oxidation during welding or brazing operations.

Forehand welding.—A method of welding in which the filler rod precedes the flame, being added to the pool of molten metal in front of the flame.

Malleability.—The property which permits of extension or shaping of a metal without fracture by hammering or rolling.

Manifold.—A header with outlets or branches to which several cylinders of gas may be connected to supply gas for a number of outlets.

Melting point.—The temperature at which a metal changes from the solid to the liquid form.

Oxide.—A coating or scale formed on metal due to its combination with oxygen.

Penetration.—The depth of fusion obtained in a welded joint.

Preheating.—The heating of a metal part preparatory to welding.

Tenacity.—The property of cohesion of particles of a metal, which tends to resist a tearing force.

Weld metal.—The metal in the joint which has been melted in making the weld including both the added and base metal.

20. Safety precautions.—The following precautions should be observed by all workmen who do welding or cutting with the electric arc or blowpipe flame:

a. Protection of the eyes.— Goggles, spectacles, or helmets, with colored lenses, should always be worn when welding or cutting. This is necessary in order to safeguard the eyes against the harmful light rays encountered and to prevent particles of hot metal from entering the eye. After welding steel for a short time, the welder will find small particles sticking to the lenses. These particles are iron oxides which would cause injury to the eye if lenses were not worn. The color of the lenses must be such that the harmful rays of light encountered will be filtered out in order to prevent eye strain and at the same time make it possible to see the metal clearly. The Noviweld or Excelolite lenses are recommended for all welding purposes, and the following table gives the proper shade numbers for the various classes of work:

TABLE III.—*Table of lens shades for various welding operations*

Shade No.	Recommended use
4	Light gas welding.
5 or 6	Heavy gas welding.
10	Metallic arc welding (up to 250 amperes).
12	Metallic arc welding (above 250 amperes).
14	Carbon arc welding and cutting.

(1) The choice between the use of goggles and spectacles for blowpipe welding rests, to a certain extent, upon the welder. However, well-ventilated goggles constructed of lightweight material offer many advantages over the spectacles. Spectacles or goggles with metal parts should be so arranged that no metal will come in contact with the skin.

(2) For electric arc welding, the lenses are mounted in a helmet constructed of a strong fiber material that provides protection for the face and head. This protection is necessary, due to the fact that the ultraviolet rays produced in the arc will cause painful burns to the skin.

(3) When wearing goggles, spectacles, or helmets, they should be adjusted so the head band or ear bows will hold them firmly against the face without undue pressure. The head bands for goggles should rest lightly on the ears and then pass down around the back of the head at the base of the skull. If the goggles have ear bows, the bows should be bent so they will not press too hard against the ear at any one place. The lenses should be kept clean at all times to prevent eye strain and allow the work to be clearly seen.

(4) If the goggles are comfortable but the eyes feel strained, a doctor or oculist should be consulted for corrections. It is also recommended that goggles be sterilized after being used if they are to be worn by other persons.

b. Fire hazards.—(1) Welding or cutting should not be undertaken in areas where fire is forbidden, nor should work of this nature be performed near inflammable materials unless proper precautions are taken to prevent ignition. In any form of welding or cutting, hot slag, sparks, and globules of molten metal are formed and sometimes fly appreciable distances. When possible, inflammable materials attached to or near equipment requiring welding, cutting, or brazing should be removed. If it is not considered practical to remove these parts, a suitable shield of asbestos or other effective heat-resisting material should be used to protect them. A fire guard should also be stationed near by with a fire extinguisher.

(2) When making repairs on an airplane, requiring the use of an open flame, ample precautions must be taken to prevent fire. Unless otherwise directed by the engineer officer or his authorized representative, the airplane being repaired should be moved to the outside of hangar or near the door, so that it could be quickly moved to the outside in case of fire. It must also be a safe distance from other aircraft or equipment considered inflammable. If welding is to be done in close proximity to the gas tank, it should be drained and filled with water.

c. Inflammable or explosive substances.—In the heating, welding, or cutting of tanks that contain or have contained inflammable or explosive substances, the following recommendations must be carefully observed to prevent danger of explosion:

(1) Never attempt to weld, cut, braze, solder, or otherwise heat a container filled with an explosive or inflammable substance.

(2) Never attempt to weld, cut, braze, solder, or otherwise heat an empty container that previously contained an inflammable or explosive substance, unless all such substance and its latent fumes have been completely removed and the container is well vented.

(3) Never attempt to weld, cut, braze, solder, or otherwise heat closed cylinders or jackets unless such units are amply vented.

d. Fumes and gases generated by welding, etc.—The fumes of burning paint are usually laden with particles of lead or zinc, which are poisonous, as are the fumes generated during the brazing, welding, and cutting of brass, zinc, and galvanized parts. Extreme care must therefore be taken to avoid inhaling these gases in any appreciable quantity.

e. Ventilation.—When welding in an inadequately ventilated place, the fumes or gases generated, or the reduction of the oxygen in the air by the flame, may overcome the operator. For this reason, welding should not be accomplished in such places, unless adequate forced ventilation is provided or the operator is supplied with a suitable signaling device and an assistant is stationed nearby to render aid when necessary.

f. Handling the torch.—(1) The torch flame should always be kept within the field of vision and care exercised in directing the flame to avoid accidental fire or personal injury by the flame or sparks.

(2) In the event of flashback, both valves on the torch must be shut off immediately; first the acetylene, then the oxygen. If a hose bursts or escaping gas is ignited at the regulator or tank at any time, the tank valve must be shut off at once.

(3) When possible, light the torch from a lighter, gas jet, or similar device. Should it become necessary to use a match, light it, lay it on some noninflammable substance, and then light the torch by holding the tip directly into the match flame.

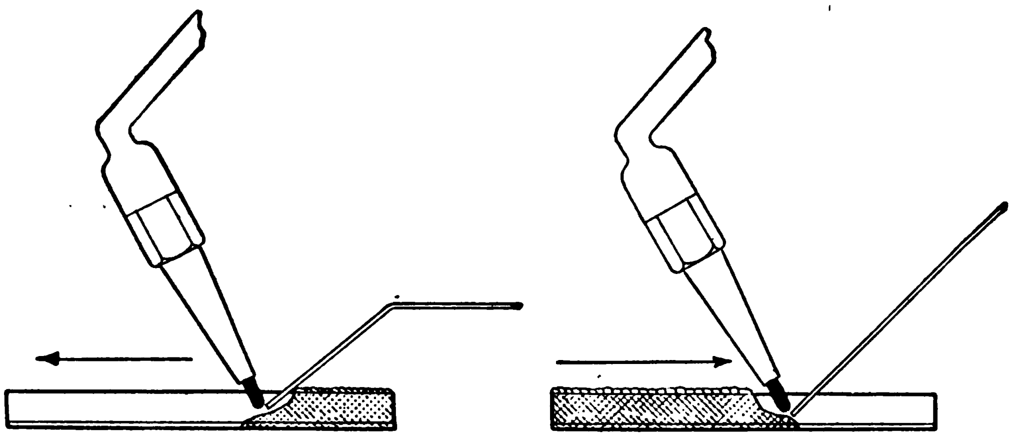
g. Use of oil.—Under no circumstances should gages, regulators, or other oxygen equipment be lubricated with oil.

h. Injuries from falling parts.—Care must be used when cutting sheets, bars, etc., to prevent the part that is cut off from falling on the operator or helper.

i. Hot metal.—Hot metal must never be left where it will form a hazard. A chalked sign indicating its presence should be used to serve as a warning when necessary.

21. Torch welding technique.—*a.* The welder should position his work as conveniently as possible for making a weld. Better work may be accomplished with the parts to be welded in a flat position, or slightly inclined, so the weld will run horizontally or slightly upward. The torch should be held lightly yet firm enough to allow accurate control. Manipulation of the torch should be made with a wrist and forearm movement. When using a welding rod, it should be held in the hand opposite from the torch and gripped close enough to the end to allow accurate placement in the weld.

b. There are two methods of welding with a torch flame: the forehand and backhand methods (fig. 18).



① Backhand welding. ② Forehand welding.

FIGURE 18.—Methods of welding with the oxyacetylene torch.

(1) *Forehand welding.*—The forward or forehand method of welding is preferable for thin wall tubing and light gage sheet metals. The torch head is tilted back from the flame to allow it to point in the direction that the weld is progressing. The angle at which the flame should contact the metal will depend upon the type of joint, position of the work, and kind of metal being welded, although between 30° and 60° is general practice. When a filler rod is used in making a weld by the forehand method, it should be added to the pool of melting metal, in front of the torch flame. The angle of the rod in relation to the torch and work will vary for different operations, but in all cases it must be added to the weld by holding the end down into the molten pool of base metal formed by the fusing of the joint edges. Holding the rod above the pool and allowing it to

melt and drop into the weld will trap impurities floating on the surface of the molten metal, causing a poor joint.

(2) *Backhand welding.*—The backhand method of welding is generally preferred for metals of heavy cross section. The work may be held in any position except for welding seams running vertically. By the use of this method, the large pool of melting metal that must be maintained is more easily controlled and the required depth of fusion in the base metal is also easier to obtain. In backhand welding, the torch head is tilted back toward the unfinished weld at an angle of approximately 70° to the seam, with the flame pointing toward the finished weld. The welding rod is added between the torch flame and finished weld. The flame is moved back and forth across the seam with a semicircular motion, breaking down the edges and side walls of the base metal and fusing them to the required depth. The end of the filler rod is held in the pool and given a slight alternating movement with the flame when adding metal to the weld. This rod movement must be controlled so that the melting metal from the pool will not be pushed over on metal which is not in a proper state of fusion to receive it.

22. Selection of tip size.—*a.* The selection of the proper size tip depends upon the thickness of metal and rate at which the heat will be conducted or radiated. In some instances, the rate of conduction and radiation of heat is effected by the location of the parts to be welded. Heavy parts will also conduct the heat more rapidly from the weld area than light parts, and to offset these conditions a larger tip must be used. In any case, the tip size should not be greater than is required to produce sufficient heat for the weld to be made. If the flame is too large, the metal will be overheated, resulting in an excess amount of scale, abnormal expansion, etc. In the case of light metals, overheating often results in the burning of holes, excess penetration, and large tears of weld metal protruding on the opposite side from which the weld is made. If the tip is too small, the volume of flame will not be sufficient to obtain proper fusion, which will result in a layer of oxide between the base and weld metals or the forming of successive layers of unfused weld metal known as cold shuts.

b. Torch manufacturers furnish tables giving the approximate sizes of tips for welding different thicknesses of metal. In case the manufacturer's table of tip sizes is not available, the approximate size of tip for iron or steel may be selected by gaging the tip orifice and referring to the following table:

TABLE IV.—*Tip sizes*

Metal thickness (inch)	Diameter of hole in tip (inch)	Drill size (No.)
0. 015 to 0. 031	0. 026	71
. 031 to . 065	. 031	68
. 065 to . 125	. 037	63
. 125 to . 128	. 042	58
. 128 to . 250	. 055	54
. 250 to . 375	. 067	51
. 375 to . 500	. 076	48

23. Types of joints and preparation of metals for welding.—*a.* The correct preparation of metals for welding is an important factor in making a sound, dependable weld. All mill scale, rust, oxides, and other impurities must be removed from the joint edges or surfaces in order to prevent their inclusion in the weld metal. The ends or edges to be welded should be prepared in a manner that will permit fusion without using an excess amount of heat. This is also necessary in order to minimize heat radiation into the base metal from the weld. Proper preparation of the parts to be joined will reduce the amount of expansion and subsequent contraction.

b. In general, there are five different types of joints used to weld the various forms of metal: butt joints, tee joints, lap joints, corner joints, and edge joints. The preparation of the metal is governed by the form, thickness, kind of metal, facilities for preparing the edges to be joined, and load stress the weld will be required to support.

(1) *Butt joints.*—Figure 19 shows the different methods of preparing butt joints for gas welding. For electric arc welding the bevel may be decreased and in some cases it is only necessary to prepare one edge.

(*a*) The joint (fig. 19①) is known as the flange butt joint and is used for sheet metal up to 0.0625 inch in thickness. The edges to be welded are turned up 80° or 90°, from 1 to 3 times the metal thickness, and these flanges are melted down and fused together to make the weld.

(*b*) The plain butt joint (fig. 19②) may be used for thickness up to ⅛ inch when welding with the oxyacetylene flame. Thicknesses up to ⅜ inch are readily welded with the electric arc, using a metal electrode, although the thicker sections will require welding from both sides with each weld penetrating ½ the metal thickness, if a full strength joint is required. Thicknesses up to ¾ inch can

be welded without beveling by using the carbon arc. This type of joint is the most economical as there is no preparation other than cleaning required.

(*c*) The edges of metals with heavy cross sections should be prepared for welding as shown in figure 19③, ④, ⑤, and ⑥. The angle of bevel for joints ③ and ④ is preferably 45° for the oxyacetylene process, while 37½° to 45° is satisfactory for metallic arc welding. The joint shown in ③ is known as a single **V** butt joint and is used for metal ⅛ to ½ inch thick where the joint can be welded from one side only. The joint shown in ④ is a double **V** type and is used for solid shapes that can be welded from both sides. This joint requires approximately one-half the amount of welding rod necessary for making the single **V** type but is more

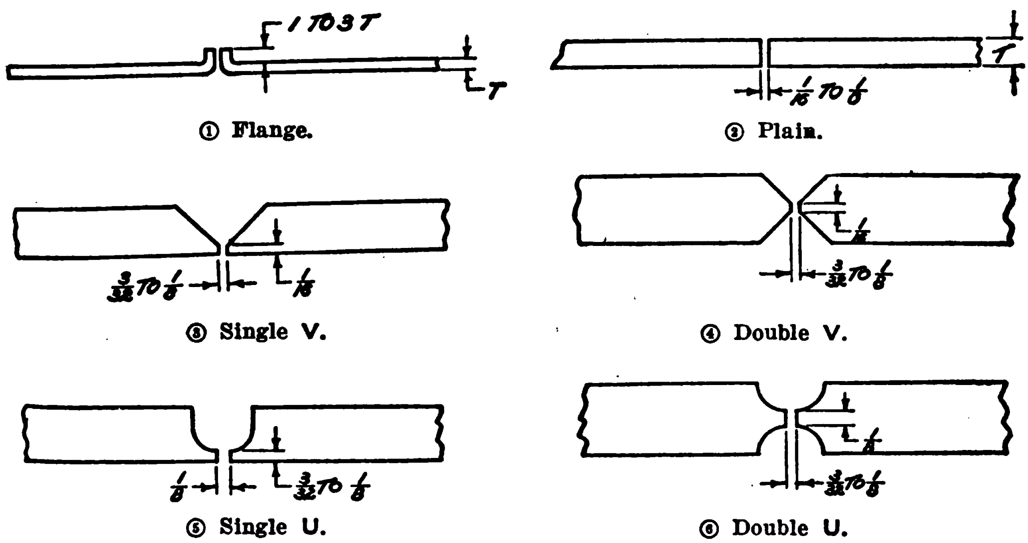


FIGURE 19.—Preparation of metals for welding butt joints.

expensive to prepare. The single **U** butt joint shown in ⑤ and double **U** type shown in ⑥ are generally preferred for solid shapes of greater thickness as they require less welding rod than the **V** type joints. All butt joints which have full penetration, good fusion, and proper reinforcement are suitable for any kind of load stresses.

(2) *Tee joints.*—Figure 20 shows the different methods of preparing metals where the end or edge of one piece is to be welded to the surface of another. Tee joints are prepared in much the same manner as butt joints.

(*a*) The plain tee joint (fig. 20①) requires no preparation other than cleaning the end of the vertical member and the surface of the horizontal member. The weld is made from each side with penetration into the root or intersection. This joint is suitable for most metal thick-

nesses used in aircraft work and may also be applied to heavier metals where the weld can be placed so that the load stresses will be transverse to the longitudinal dimensions of the weld.

(*b*) The single V tee joint (fig. 20②) is most generally used for plates and shapes up to ½ inch in thickness where the joint can be

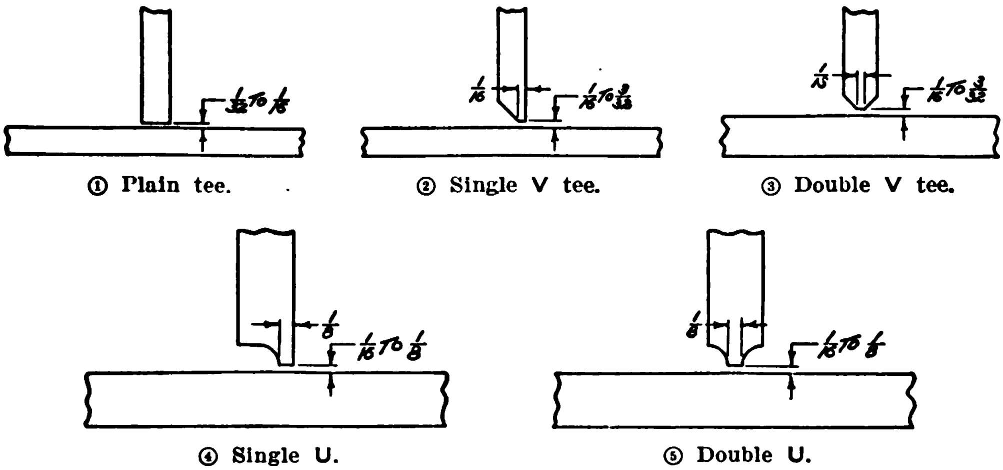


FIGURE 20.—Preparation of metals for welding tee joints.

welded from one side only. With full penetration and fusion into both members this joint is satisfactory for most normal loading.

(*c*) The double V tee joint (fig. 20③) is used for heavy plates and shapes where the joint can be welded from both sides. This joint is suitable for all types of loading, provided the weld metal is fused to-

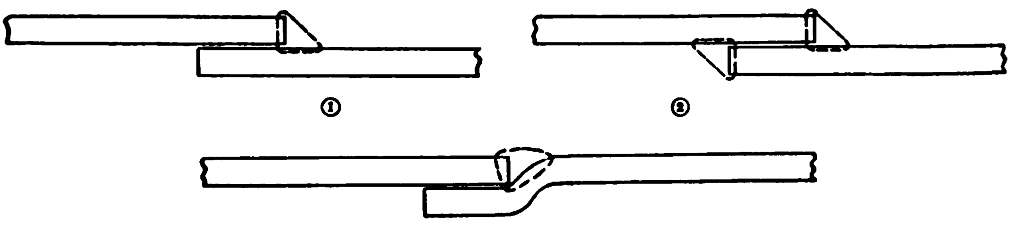


FIGURE 21.—Preparation of metal sheet for lap joints.

gether at the end of the branch member and penetration is obtained in both members.

(*d*) The single U joint (fig. 20④) is used for plates 1 inch thick and heavier where the weld can be made from one side only. This form of joint is more expensive to prepare as it requires machining, although less filler rod is necessary than when welding a single V tee joint. With full penetration and fusion into each member it is suitable for all usual types of loading.

(*e*) The double **U** joint (fig. 20⑤) is suitable for all plates and other solid shapes of heavy cross section where the joint can be welded from both sides. The weld metal must, however, penetrate into both members. This joint will withstand heavy loads of all types and requires less filler rod than the double **V** tee joint.

(3) *Lap joints.*—Figure 21 shows the different types of lap joints. These joints are used extensively in the construction of articles of equipment fabricated from sheet and plate, although they are not as efficient as the butt welds for transmission of load stresses. The lap joints are also used in the welding of structural shapes for buildings. etc. They are more efficient when the weld can be placed so the load stress will be transverse to the line of weld.

(*a*) The joint shown in figure 21① is used for sheet, plate, and structural shapes where the loading is not severe. This method is also

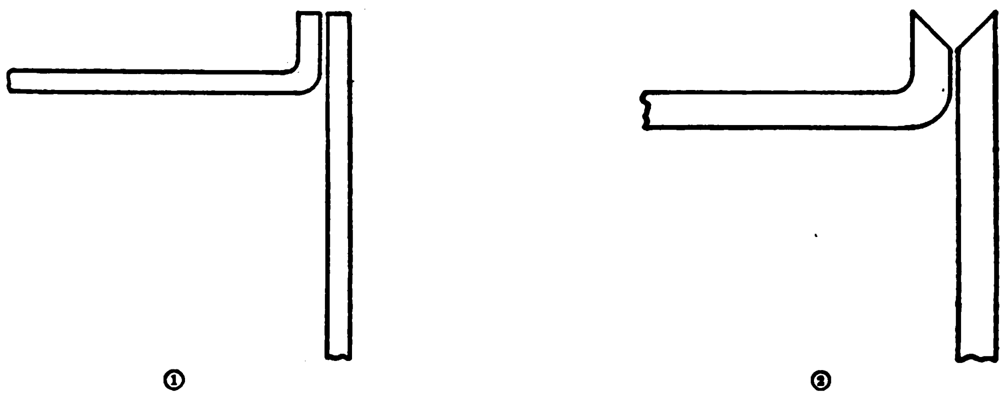


FIGURE 22.—Types of edge joints for sheet and plate.

adaptable for telescope splices in steel tubing and in this case is superior to a butt joint.

(*b*) The double weld lap joint (fig. 21②) is used for sheet and plate where greater strength is required than is obtainable with a single weld. This joint when properly welded will develop the full strength of the sheet or plate in all ordinary thicknesses.

(*c*) The offset or "joggled" lap joint (fig. 21③) is used for sheet and plate where it is desired to have a lap joint with one side of both plates or sheets in the same plane. This joint gives more even distribution to load stresses than the single or double bead weld but it is more difficult to prepare.

(4) *Edge joints.*—Figure 22 shows the preparation of sheet and plate for an edge weld. This joint is not ordinarily employed where high joint strength is required. It is, however, often used for fittings made up of two or more pieces of sheet stock, where the edges must be fastened together, as an arrangement of this kind is not subjected to

high stresses. Edge joints are also used in tanks that are not to be subjected to high internal pressures. Joint shown in ① is generally used for thin sheets while the one in ② is adaptable to thick sections.

(5) *Corner joints.*—Figure 23 shows the different types of corner joints used in the construction of boxes, tanks, and other articles fabricated of sheet and plate.

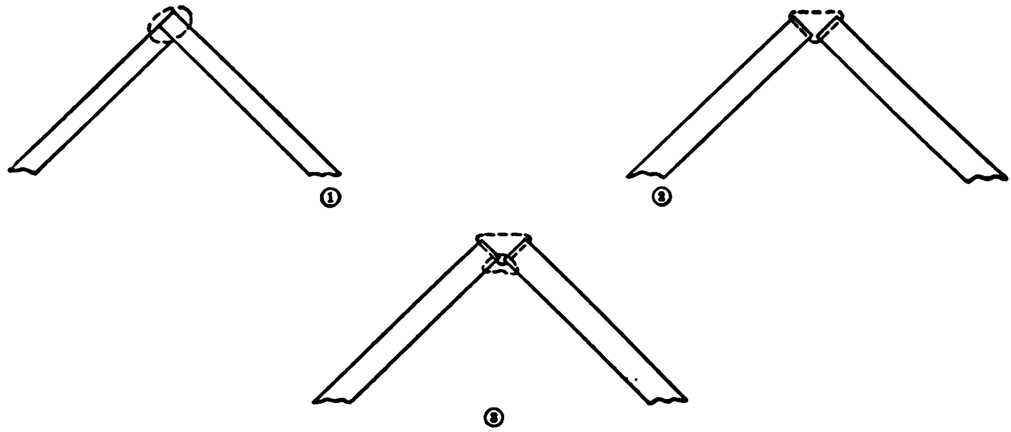


FIGURE 23.—Types of corner joints for sheet and plate.

(*a*) The closed type joint (fig. 23①) is used on the lighter gage metals where the joint is subjected to moderate stresses. The joint is made with the addition of little or no filler rod as the edge of the overlapping sheet is melted down and fused to form the bead.

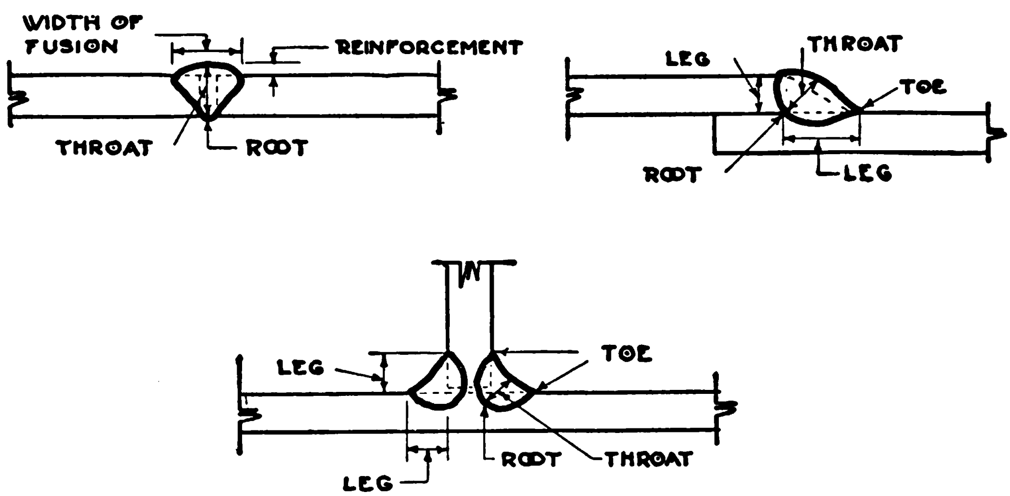


FIGURE 24.—Weld metal nomenclature.

(*b*) The open joint (fig. 23②) is used on heavier sheet for the same purpose as the closed type joint. This joint is made by fusing the two edges at the inside corner and adding sufficient filler rod to give a well-rounded bead of weld metal on the outside.

(*c*) The open joint (fig. 23③) may also be used for heavier plate and when properly welded is suitable for all usual load stresses. The joint is welded on the outside in the same manner as described for joint shown in ②, and a light concave bead is laid on the inside to give a greater thickness through the weld metal.

24. Weld metal nomenclature.—For convenience in specifying certain requirements of a welded joint, the different parts of the weld metal are shown in figure 24 and defined as follows:

a. The *fusion zone* is the width of the weld metal, including the depth of fusion in the base metal on each side of the joint.

b. The *leg* is the dimension of the weld metal extending on each side of the root of the joint.

c. The *reinforcement* is the metal added to give the weld a greater thickness in cross section.

d. The *root* is the depth that fusion penetrates into the base metal at the joint.

e. The *throat* is the distance through the center of the weld from the root to the face.

f. The *toe* is the edge of the fusion zone in the base metal on each side of the weld.

25. Welding positions.—There are four general positions in which welds are required to be made. These positions are shown in figure 25 and are designated as flat, vertical, horizontal, and overhead.

a. Flat position welding.—When a weld is made with the parts flat on the table, or inclined at an angle less than 45°, it is designated as being flat. In this position the weld may be made by the forehand or backhand method depending upon the thickness of metal.

b. Vertical position welding.—When the parts are inclined at an angle more than 45°, with the seam running vertically, it is designated as a vertical weld. While welding joints in this position with a blowpipe flame, the weld should be made from the bottom with the flame pointed upward at an angle of 45° to 60° to the seam. The rod is added to the weld in front of the flame as in ordinary forehand welding.

c. Horizontal position welding.—When a weld is made with the parts in a vertical position, or inclined at an angle of more than 45° with the seam running horizontally, it is called a horizontal weld. Seams in this position may be welded by means of either the forehand or backhand technique. In either case, the flame should point slightly upward in order to help prevent the melting metal from running to the lower side of the seam. The rod when used should be added to the weld at the upper edge of the fusion zone, as it dissipates some of

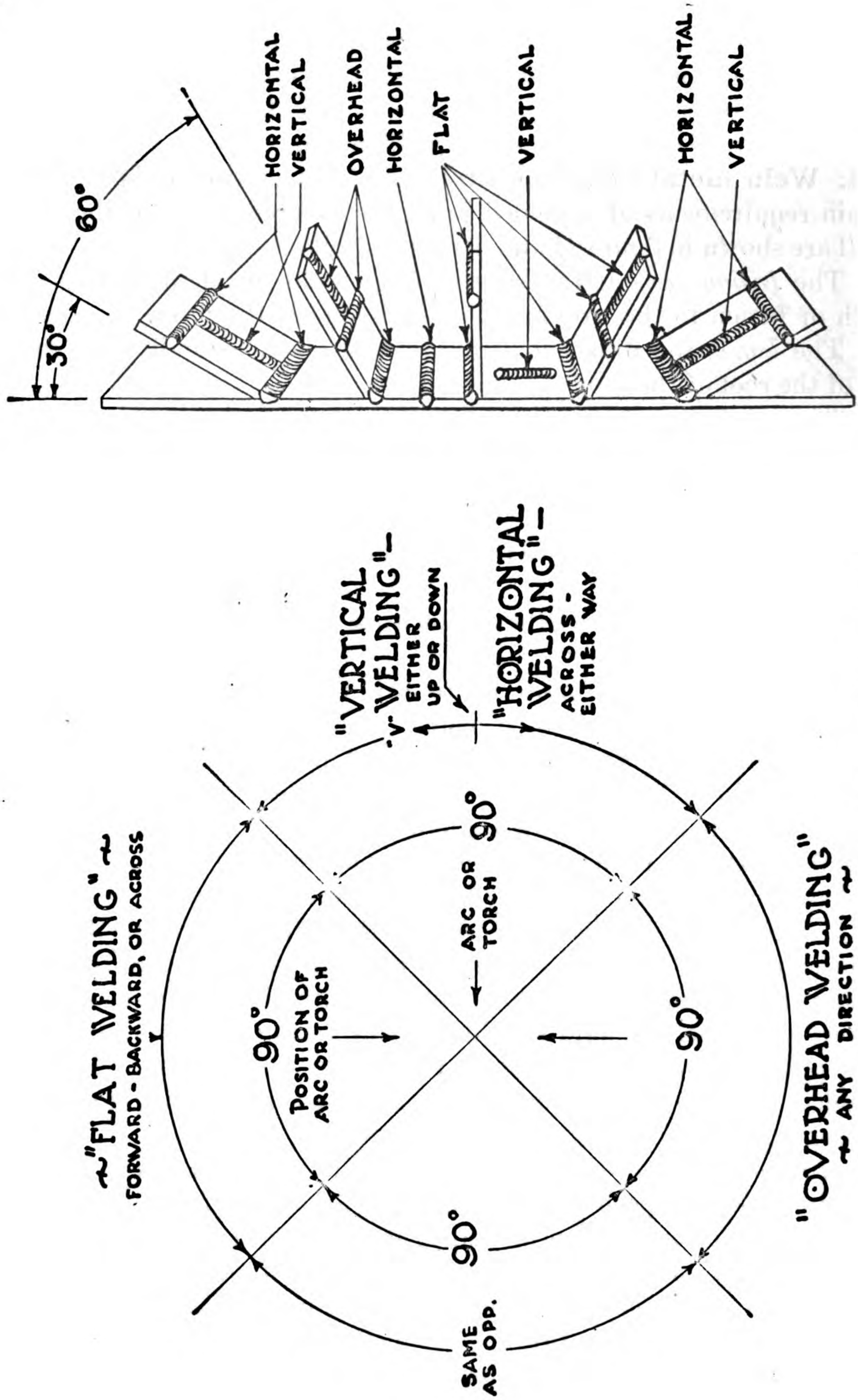


FIGURE 25.—Welding positions.

the heat and provides enough chill to aid in holding the melting metal in place.

d. Overhead position welding.—When a weld is made on the under side of the work with the seam running horizontally, or in a plane that requires the flame to point upward from below, it is called an overhead weld. When welding seams in an overhead position, either the forehand or backhand technique may be used. In each case the torch flame must be pointed upward and held at approximately the same angle as used for welding in a flat position. The volume of flame used for overhead welding should not exceed that required to obtain good fusion of the base metal with the filler rod. A large pool of melting metal should be avoided, as the metal will drip or run out of the joint.

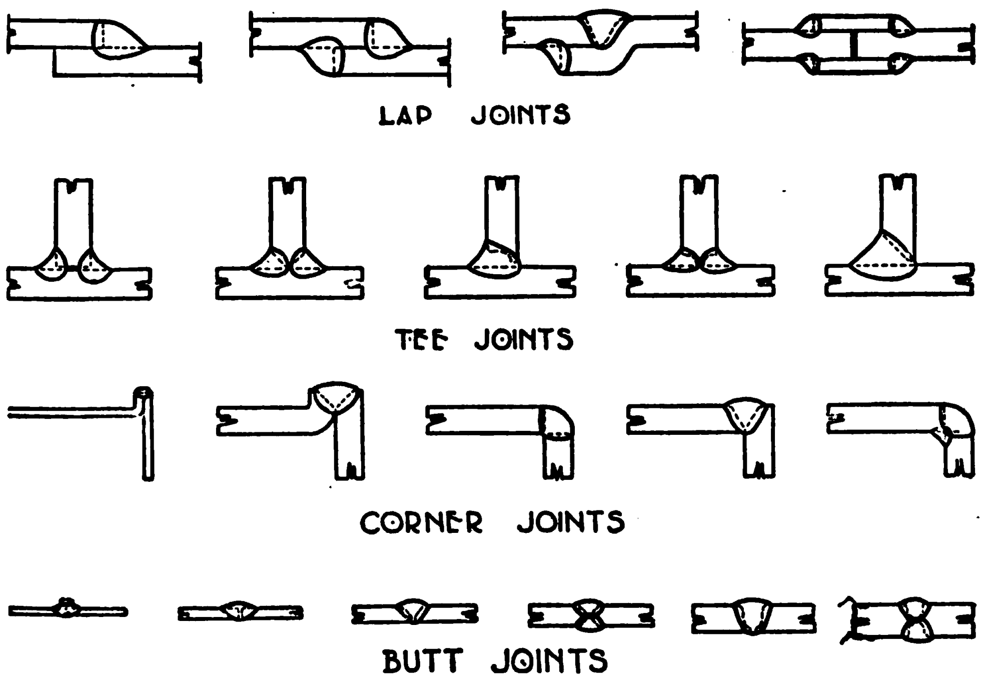


FIGURE 26.—Correct weld metal forms.

26. Correct forming of a weld.—*a.* The form of the weld metal has considerable bearing upon the strength and fatigue resistant of a joint. Improperly made welds may be 50 percent or more below the strength for which the joint was designed.

b. Low strength welds are generally the result of insufficient penetration; undercutting of the base metal at the toe of the weld; poor fusion of the weld metal with the base metal; trapped oxides, slag, or gas pockets in the weld; overlap of the weld metal on the base metal; too much or too little reinforcement; and overheating of the weld. The correct forms for the various types of welds are shown in figure 26. In this figure, the heavy lines indicate the fusion of the weld

metal with the base metal. Figure 27 shows the most common faults in the different types of welded joints. These forms are due to faulty welding technique, lack of experience, or carelessness on the part of the welder. Any weld having an appearance such as indicated in this illustration should be rejected.

27. Chemical and physical changes produced by welding.—In the working of metals by the application of heat, there are certain conditions that must be taken into consideration.

a. Chemical changes.—A chemical change takes place when a substance is added to or taken away from the metal. The intense heat of the electric arc or oxyacetylene flame, if directed upon a piece of metal and held long enough in one place, will cause the loss of one or more of its constituents. A chemical change produced in this way will have a marked effect upon the physical properties of the metal, usually reducing its tensile strength, ductility, and yield point. The addition of some element to the metal, or an appreciable increase of one or more of its constituents, during welding, will also generally result in a loss of strength properties.

b. Physical changes.—A physical change is one which a substance undergoes without alteration of its chemical structure. Physical properties of a metal which are factors in physical changes of interest to the welder are the melting point, rate of expansion and contraction, and heat conductivity.

(1) *Melting point.*—The melting point is the temperature at which a metal changes from a solid to a liquid state. Not all metals melt at the same temperature, and an alloyed element in a metal will often lower the melting point. It is essential that a welder know the approximate melting point of the various metals, as there are many cases in which metals having a difference of several hundred degrees in their melting points are welded together. The melting points and other pertinent properties of the various metals in common use are given in table V. It should be understood that melting points above 2,000° F. are not known exactly and often vary as much as 5° or 10°. The melting points given for the alloyed metals vary according to the percentage of the alloying element and should be taken as approximate only.

(2) *Expansion.*—Metals are sensitive to the action of heat and cold. They expand under the action of heat with a consequent increase in length, thickness, and width unless restrained in one of these dimensions. If the temperature of a metal body is raised progressively throughout the mass and is lowered in the same way, the force of expansion generally has no ill effects, such as distortion

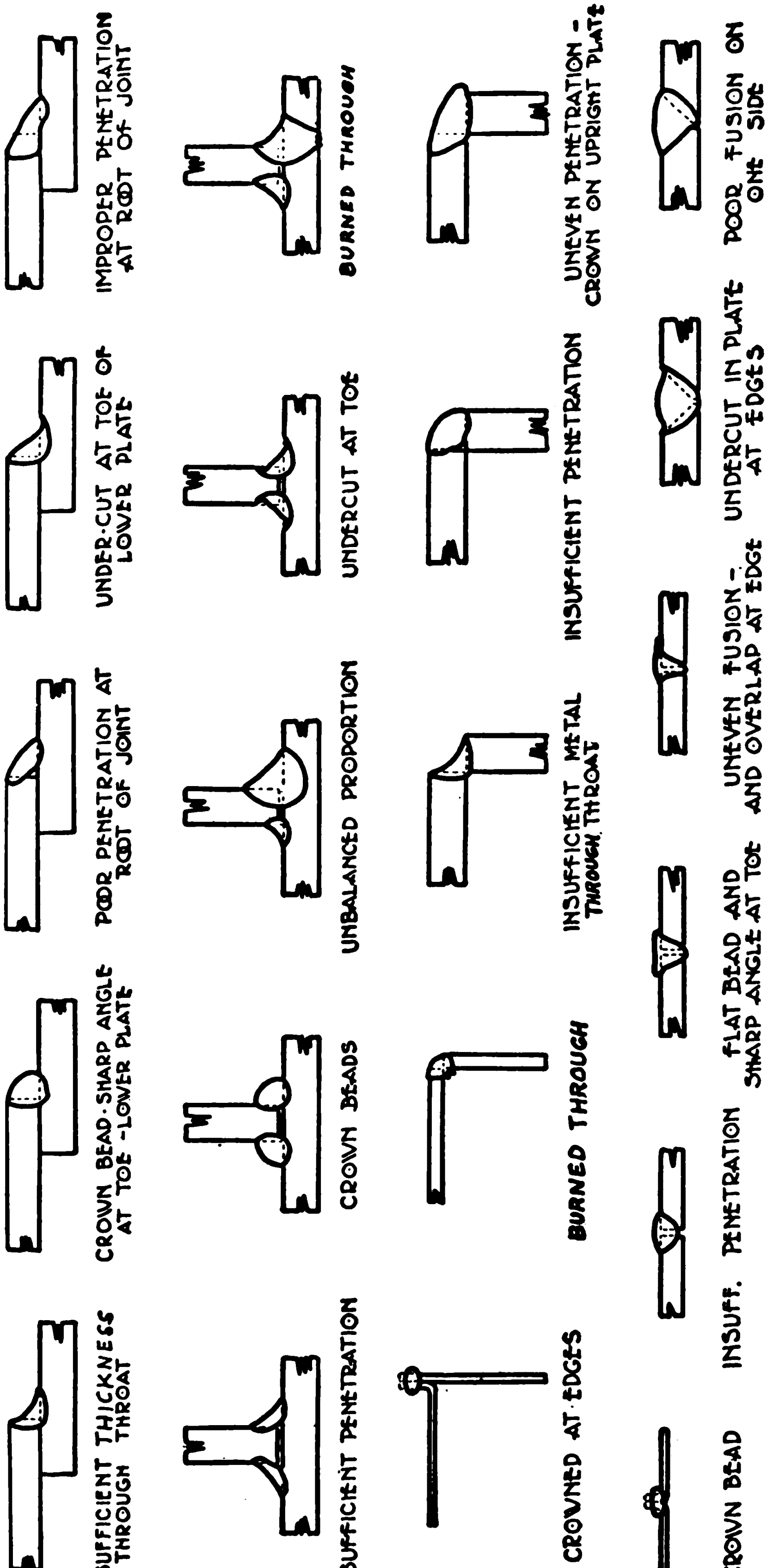


FIGURE 27.—Common faults in the weld metal formation of various joints.

or breakage, since the action is uniform. This is not true, however, when heat from the welding flame is concentrated on a metal body at one point. In this case the metal in the heated area tries to expand at the point of heat application, and the part which opposes it either distorts out of shape, breaks, or is severely strained. Each kind of metal will expand a definite amount for each degree of rise in temperature. The expansion, per degree rise in temperature, per inch has been accurately computed for several different metals and is termed the coefficient of expansion. The coefficients of expansion for the most common metals are given in table V, and by the values listed the amount that a piece of metal will expand at a centain temperature can be determined by means of the following formula:

$$\text{Expansion (in inches)} = A \times B \times C$$

where

A = length of piece in inches.
B = temperature in ° F.
C = coefficient of expansion.

TABLE V.—*Properties of metals*

Kind of metal	Melting point (°F.)	Linear expansion (per inch per °F.)	Heat conductivity (percent)
Aluminum	1, 218	0. 00001234	48
Antimony	1, 166	. 00000627	4. 2
Bismuth	611	. 00000975	1. 8
Brass	1,650 to 1,850	. 00000957	15 to 30
Bronze	1,650 to 1,932	. 00000986	----------
Cadmium	610	----------	----------
Copper	1, 981	. 00000887	74
Gold	1, 930	. 00000887	53. 2
Iron, gray cast	2,200 to 2,400	. 00000556	11. 9
Iron, wrought	2, 834	. 00000648	11 to 18
Lead	621	. 00001571	8. 5
Magnesium	1, 204	----------	37. 6
Molybdenum	4, 620	----------	----------
Monel metal	2, 480	. 00000777	3. 5
Nickel	2, 646	. 00000695	14
Platinum	3, 191	. 00000479	17
Silver	1, 761	. 00001079	100
Steel	2,480 to 2,786	. 00000636	6 to 14
Tin	449	. 00001163	15. 2
Tungsten	6, 152	----------	----------
Vanadium	3, 128	----------	----------
Zinc	787	. 00001407	28. 1

[1] Values based on the heat conductivity of silver which is considered as 100 percent.

If no provision is made for the metal to expand on heating, the stress set up will be proportional to the compression strength of the metal. This relation will, of course, only be true up to the temperature at which the metal will yield to pressure. Other forms, such as bar, plate, pipe, structural shapes, and castings, will upset in the heated area proportionally to the amount of expansion which will result in a reduction in dimensions, distortion, or breakage. The effects of expansion can be offset in most cases by preheating or making proper allowance for the metal to expand without being restrained. Proper welding sequence in the construction of an article of equipment is also a practical way of providing for expansion.

(3) *Contraction.*—Contraction is the reverse of expansion; that is, upon cooling from the welding temperature, the metal will con-

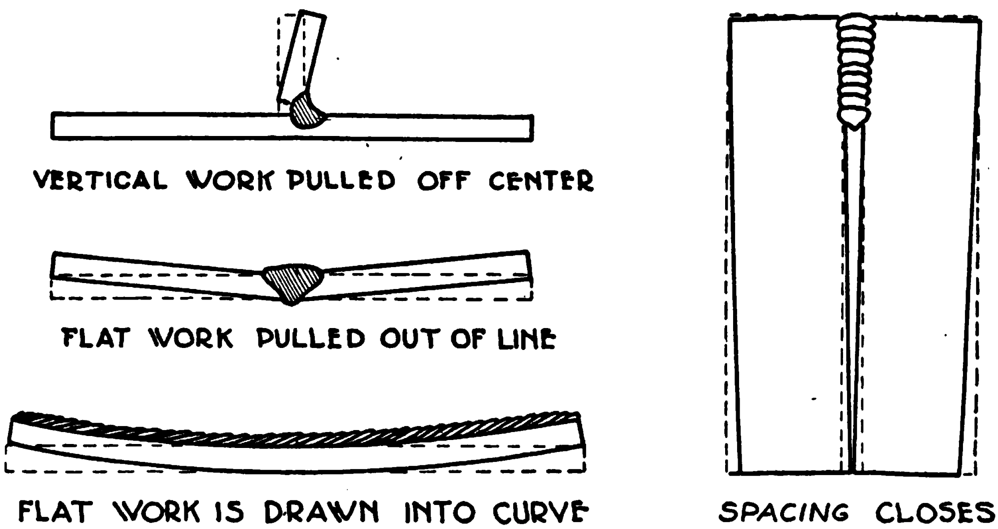


FIGURE 28.—Results of weld metal shrinkage.

tract as much as it expanded, if the temperature is uniform throughout the part and contraction is not restrained. If contraction is restrained, the metal part will be pulled out of alinement, or a high stress will remain in it which will endanger the holding power of the weld or cause the metal to break at a weaker point. Figure 28 shows how contraction of the weld metal will pull the parts out of alinement when no provision is made to prevent it. The effects of contraction can best be controlled by slow, even cooling for parts which have been preheated. In the construction of an article of equipment, provision for the contraction of the weld metal can usually be made in such a way as to cause the shrinkage of the weld to pull the members into alinement. Jigs are often used to hold the parts, although in this case there will be some stress remaining

in the weld or adjacent metal unless the part is stress-relieved by subsequent heat treatment.

(4) *Conductivity.*—The ease with which heat travels through a substance is called its heat conductivity. Heat travels through some substances with greater ease than through others. Heat conductivity of metals must be considered with respect to welding for the following reasons:

(*a*) A considerable amount of heat is conducted away from the point of application and is lost. Therefore, metals which have a high conductivity will require a greater amount of heat, other factors being equal.

(*b*) The higher the conductivity the more extensive and hotter will become the heated area surrounding the weld. Consequently, a greater amount of expansion is to be expected with metals of high conductivity, other factors being equal.

c. Influence of elevated temperatures on strength of metals.—The strength of certain metals becomes practically zero when they are raised to a temperature which is still far below their melting point. Aluminum alloys, brass, bronze, copper, cast iron, and some of the alloy steels are quite brittle at temperatures near their melting points, and if strained at these critical temperatures will break or check in the heated area. Table VI illustrates the effect of heat upon the strength of various common metals, and the values are given in percent of the maximum strength.

TABLE VI.—*Influence of temperatures on the strength of metals*

Metal	Temperature (° F.)							
	210°	400°	570°	750°	930°	1,100°	1,300°	1,475°
	Percent of maximum strength							
Aluminum	90	75	50	20	8	------	------	------
Bronze	101	94	57	26	18	------	------	------
Copper	95	85	73	59	42	------	------	------
Cast iron	------	100	99	92	76	42	------	------
Cast steel	109	125	121	97	57	------	------	------
Structural steel	103	132	122	86	49	28	------	------
Wrought iron	104	112	116	96	76	42	25	15

28. Methods of reducing distortion and residual stress.—The method used to minimize distortion and residual stress in welding varies with the different kinds of metal. Shape and size of the pieces to be welded also have a definite bearing on the final result.

a. Joints in sheet metal should be welded in a jig when it is possible to do so. A properly designed jig will hold the edges in alinement and minimize the flow of heat into the sheet, thereby reducing the amount of expansion and subsequent contraction. The metal should not be clamped so tight in the jig that normal contraction will be restrained. The edges to be welded should be spaced apart an amount equal to the calculated shrinkage of the weld. For butt joints the edges may be set parallel and either tack welded at regular intervals, as shown in figure 29① or spaced as shown in ②. In the latter case, the amount of spacing will depend upon the kind of metal being welded but will range from 1/8 to 3/8 of an inch for each foot of seam length. The method ② is preferable for flat sheets and longitudinal seams of cylindrical shapes, while the first method should be used for making short, straight seams or the curved seams on tubing, cylinders, tanks, etc. Figure 30 shows a type of jig that can be used for butt joints in flat sheet as well as the longitudinal seams of cylindrical shapes.

b. Figure 31 shows the use of angle iron for making temporary jigs for welding butt and corner joints in sheet metal. The jig shown in figure 31① consists of four pieces of angle iron. The angles used to support the work on the under side may be bolted or welded together, and a recess 1/32 to 3/64 inch deep and 1/2 to 3/4 inch wide should be machined in the center as shown in the figure. The jig shown in ② is used for welding corner joints and consists of three pieces of angle iron. The edge of the piece used to support the work on the under

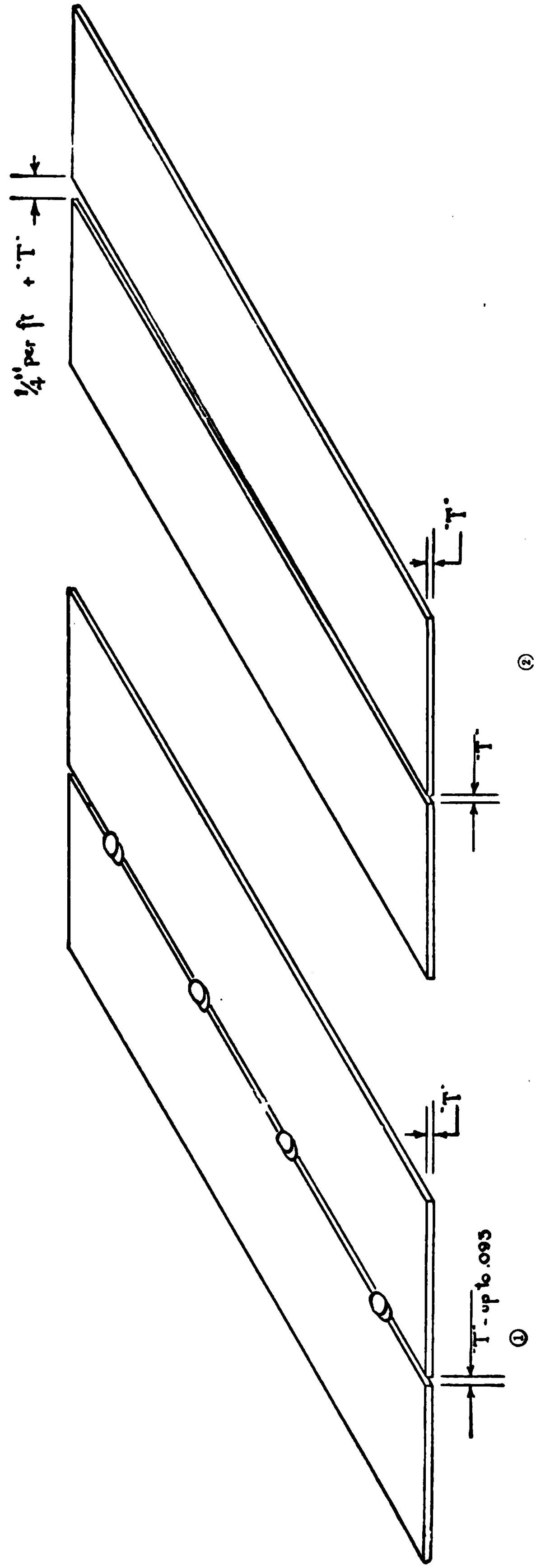


FIGURE 29.—Methods of providing for contraction in butt joints.

side must be ground or machined off to provide about $\frac{1}{16}$ inch clearance for the joint, so that fusion can penetrate through the base metal at this point. C clamps are used with these jigs to hold them in place on the metal.

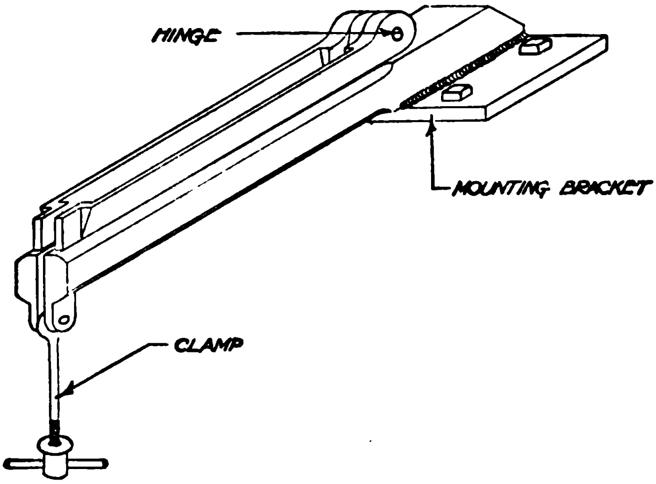
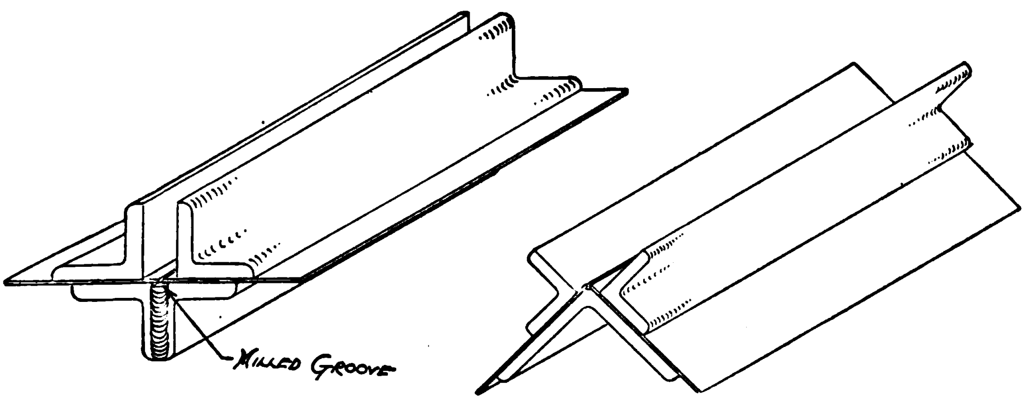


FIGURE 30.—Welding jig for sheet metal butt joints.

c. When it is impossible to design a jig for the work, and the metal is held in such manner that normal expansion and contraction are restrained, the edges of the sheet may be bent up at the joint (fig. 32①). Another method of producing the same result is shown in figure 32②. In this case a bead is formed in each sheet, parallel to the seam, $\frac{5}{8}$ to 1



① ②

FIGURE 31.—Angle iron welding jigs for sheet metal.

inch from the joint. Either of these forms will straighten out enough on cooling to relieve the strain on the weld. Should bends of this kind be objectionable or impractical, chill plates or cold packs of wet asbestos may be placed on the metal near the joint and parallel to the seam to reduce the heat flow and subsequent expansion.

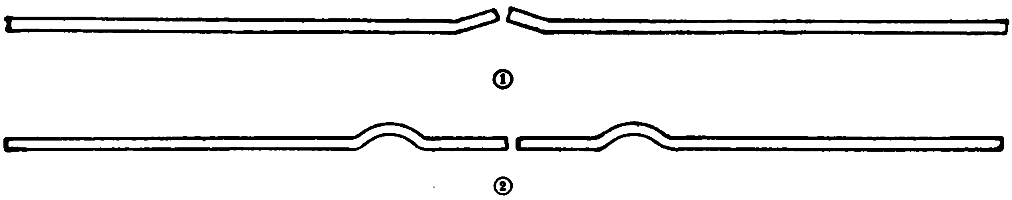
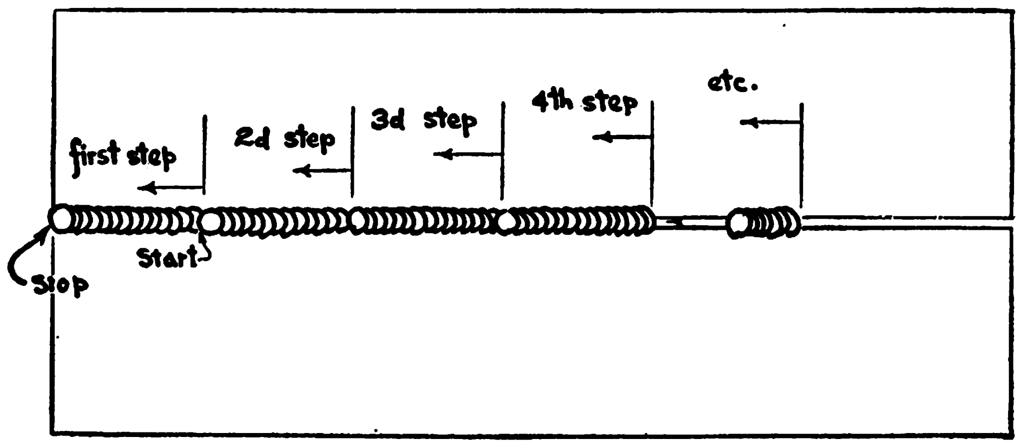
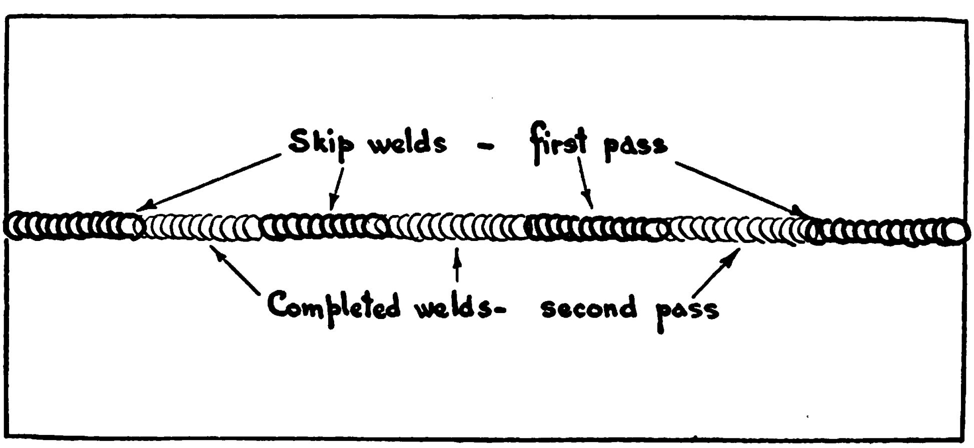


FIGURE 32.—Preparation of sheet metal to reduce contraction strains.

d. In welding plate stock where the form of the part will permit, butt joints may be set up as shown in figure 29②. If the shape of the work is such that the joint edges must be parallel, the joint should be welded by the step-back or skip-welding procedure (fig. 33① and ②). Either of these methods will reduce heat strains as the heat will be more evenly distributed over the length of the seam, thus promoting uniform expansion and contraction.



① Step-back method.



② Skip method.

FIGURE 33.—Welding procedure for reducing stress in butt joints.

e. This same plan may be used for lap and tee joints. In the production of tee joints, the welding should alternate from one side to the other as shown in figure 34. Tee joints of heavy plate should be heated to a dull red on the opposite side from which the weld is being

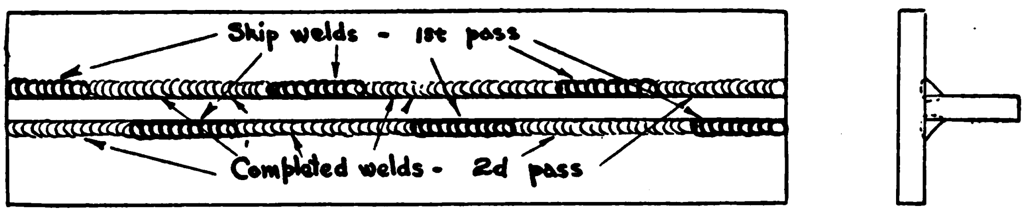
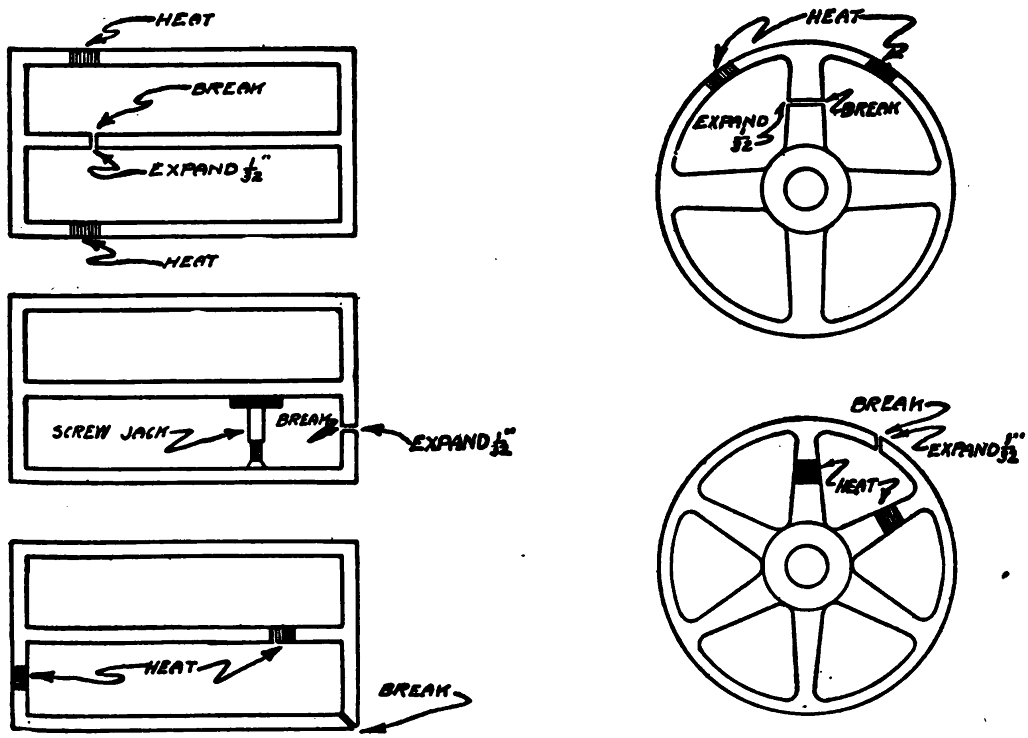


FIGURE 34.—Welding procedure for reducing stresses in tee joints.

made. A separate torch should be used, and in case the welding is done with the electric arc a multiple jet flame is preferred. This heating promotes uniform expansion on both sides of the plate, which



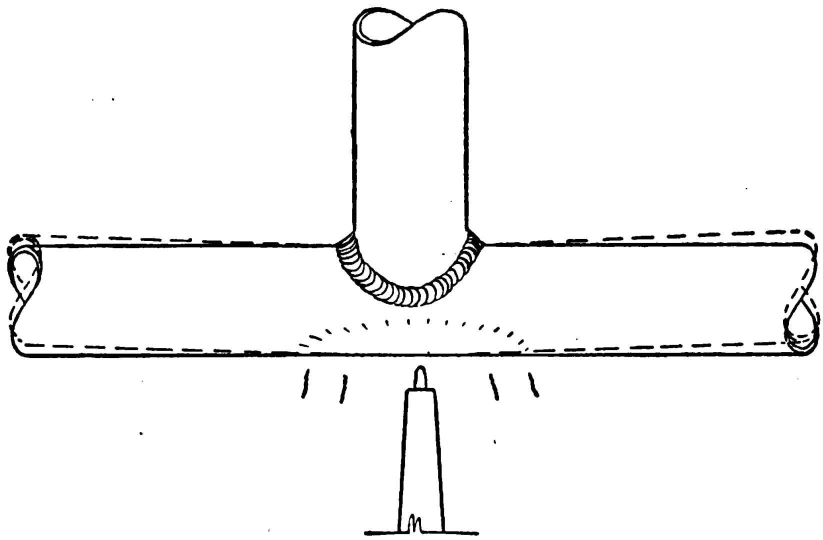
① Rectangular casting. ② Circular casting.

FIGURE 35.—Methods of providing for expansion in the welding of castings.

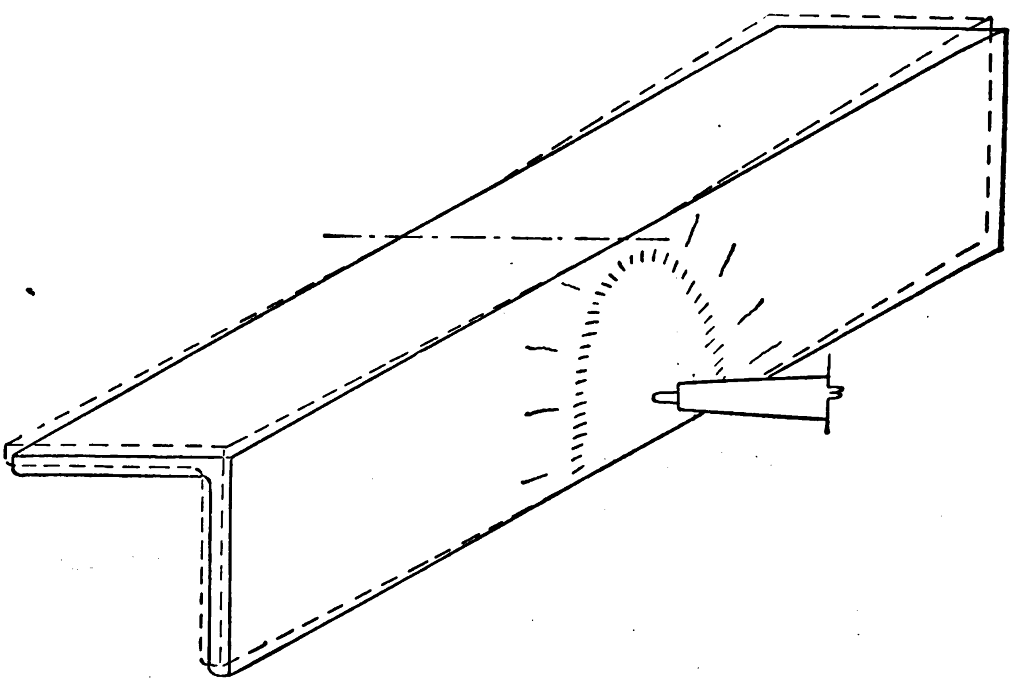
will cause even contraction and prevent the parts from being pulled out of alinement.

f. The method employed to reduce the effect of expansion and contraction in the welding of castings depends upon the kind, type, and shape of the unit as well as the nature of the break. In some

cases the entire casting will require preheating to a temperature that will prevent serious expansion strains, while in others local preheating will suffice. Whenever preheating is employed, the parts must be cooled slowly and evenly. Opposing parts may often be heated to relieve welding strains, and mechanical means are sometimes employed for the same purpose. Typical applications of this procedure are shown in figure 35.



① Tube pulled out of alinement by weld shrinkage.



② Angle iron pulled out of alinement by weld shrinkage.

FIGURE 36.—Heating with the torch flame to reduce distortion.

g. In most cases there will be some stress remaining in parts fabricated or repaired by welding. When practical, this stress should be relieved in order to have the full strength of the weld and base metal. Heat treatment is the most reliable method of stress relieving, where the part can be heated in a furnace to the stress relieving temperatures, then cooled slowly and evenly. Stress relieving temperatures for some of the principal metals are listed in the following table:

TABLE VII.—*Stress-relieving temperatures for various metals*

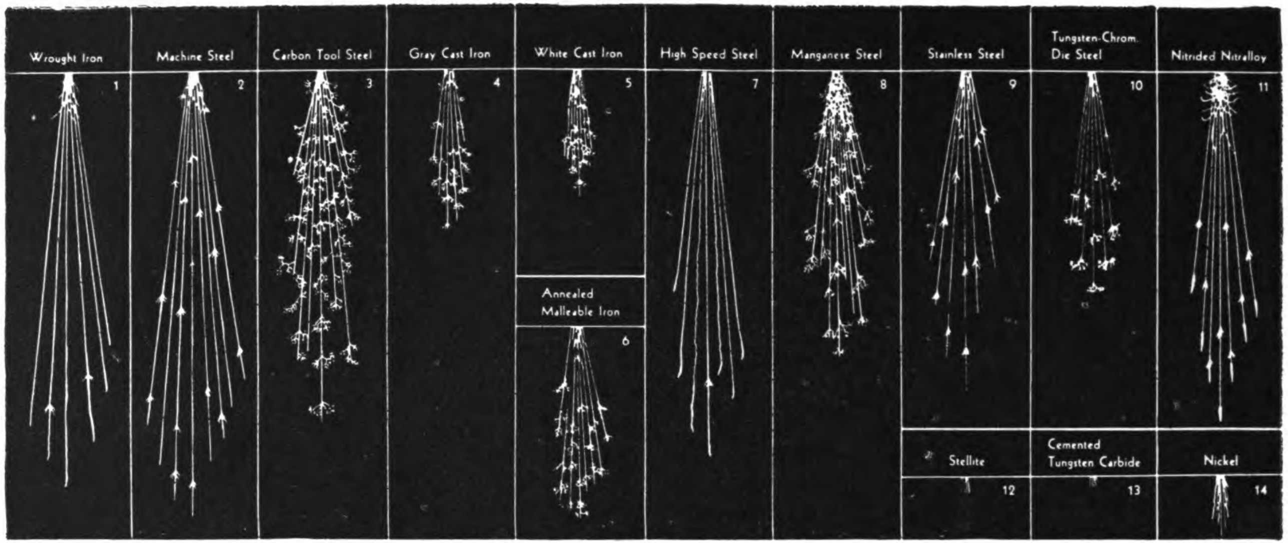
Metal	Temperature (° F.)
Carbon steels up to 0.45 carbon	1, 000 to 1, 200
Chrome-molybdenum alloy steel	1, 150 to 1, 200
Chrome-nickel stainless steel (18–8)	1, 150 to 1, 200
Nickel chromium iron alloy (Inconel)	1, 400
Aluminum and aluminum alloys	700 to 800
Gray cast iron	900 to 1, 000

In many cases, distortion can be relieved or eliminated in structures fabricated of steel tubing, angle iron, etc., by local heating with the welding flame. Figure 36① and ② shows the application of the torch for this purpose. In using this method, the metal should be brought to a red heat at the points indicated.

29. Identification of metals.—It is very important that the kind of metal be known before attempting to weld by any method in order that the correct procedure may be employed.

a. In the Army Air Forces most of the metals may be identified in storage by means of a system of markings. These markings consist of painted bands of different colors on tubes and bars while sheet stock is usually stamped with its specification number. The color markings and other identification data are given in Technical Orders.

b. In case the color markings or specification numbers are missing, ferrous metals may be identified by the characteristics of the spark stream generated by grinding them with a high speed grinding wheel. Nonferrous metals can seldom be identified in this way as they produce practically no spark when touched to a grinding wheel. When testing the ferrous metals by the spark method, the metal should be touched lightly to the wheel and the characteristics of the sparks studied. A dark background shows the sparks more clearly and should be provided when possible. It is also preferable to have samples of the various metals in order that the piece being tested for identification can be compared with the samples until one is found that will pro-



Metal	Volume of Stream	Relative Length of Stream, Inches†	Color of Stream Close to Wheel	Color of Streaks Near End of Stream	Quantity of Spurts	Nature of Spurts
1. Wrought iron	Large	65	Straw	White	Very few	Forked
2. Machine steel	Large	70	White	White	Few	Forked
3. Carbon tool steel	Moderately large	55	White	White	Very many	Fine, repeating
4. Gray cast iron	Small	25	Red	Straw	Many	Fine, repeating
5. White cast iron	Very small	20	Red	Straw	Few	Fine, repeating
6. Annealed mall. iron	Moderate	30	Red	Straw	Many	Fine, repeating
7. High speed steel	Small	60	Red	Straw	Extremely few	Forked
8. Manganese steel	Moderately large	45	White	White	Many	Fine, repeating
9. Stainless steel	Moderate	50	Straw	White	Moderate	Forked
10. Tungsten-chromium die steel	Small	35	Red	Straw*	Many	Fine, repeating*
11. Nitrided Nitralloy	Large (curved)	55	White	White	Moderate	Forked
12. Stellite	Very small	10	Orange	Orange	None	
13. Cemented tungsten carbide	Extremely small	2	Light Orange	Light Orange	None	
14. Nickel	Very small**	10	Orange	Orange	None	
15. Copper, brass, aluminum	None				None	

†Figures obtained with 12" wheel on bench stand and are relative only. Actual length in each instance will vary with grinding wheel, pressure, etc. *Blue-white spurts. **Some wavy streaks.

FIGURE 37.[1]—Characteristics of sparks generated by grinding.

[1] Courtesy of Norton Company, Worcester, Mass.

duce the same spark. Figure 37 shows the characteristics of the spark stream for several metals and the attached table describes the characteristics.

c. Aluminum and aluminum alloy may be identified by means of a simple chemical test. For this test, a sample of the material is immersed in a 10 percent solution of caustic soda and allowed to remain until the surface has been turned a dark color. If the sample is unalloyed aluminum, this color may be readily washed off with water leaving the surface bright and lustrous, whereas if it is aluminum alloy washing will not remove the stain. In the case of Alclad (aluminum alloy coated with a thin deposit of pure aluminum) this test is somewhat confusing due to the fact that the stain may be washed from the surface as in the case of unalloyed aluminum. Identification may, however, be made by observing the edges along which the sample has been cut.

d. For identification between chrome-nickel corrosion resistant steel (18-8 alloy) and nickel chromium iron alloy (Inconel), a chemical test is the most reliable. This test consists of the application of a solution consisting of 10 grams of cupric chloride dissolved in 100 cubic centimeters of hydrochloric acid to a sample that has been thoroughly cleaned. In performing the test, one drop is applied and allowed to remain in contact with the metal for 2 minutes. At the end of this period, 3 or 4 drops of water are slowly added and the sample washed and dried. If the metal is stainless steel, the copper in the cupric chloride solution will be deposited, leaving a copper colored spot, while if the sample is Inconel a white spot will result.

e. Magnesium alloys can be readily identified by a flame test. To accomplish this, the welding flame is directed on a small piece removed from the metal to be identified until it has been brought to the melting point. If the metal is magnesium alloy, it will ignite immediately and burn with a bright glow.

Section III

ELECTRIC ARC WELDING

30. General.—*a.* In electric arc welding, the heat of an electric arc is used to produce fusion of the parts. The arc is formed by bringing two conductors of electricity together, then separating them

and allowing an electric current to continue through the intervening air space. In all types of arc welding machines, this arc is formed between the work to be welded and an electrode, fixed in a suitable holder. The tremendous amount of heat concentrated on the affected area of the work and electrode end immediately brings the metal to the melting point and is also sufficient to fuse and add additional filler metal to the weld.

b. Either a metallic or carbon arc may be employed for the welding process although the former type is more generally used.

(1) In metallic arc welding, the arc is produced between the work to be welded and a metal wire or rod. The welding current is fed through these members and the circuit completed at the arc. The resultant temperatures instantly bring a small area of the base

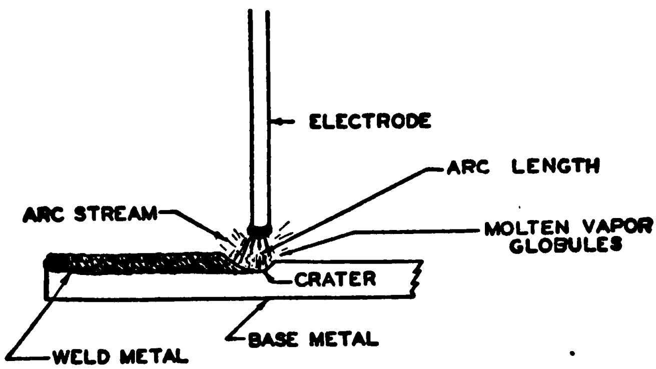


FIGURE 38.—Metallic welding arc.

metal to the melting point and reduce the tip of the rod to tiny globules of molten metal. These globules are carried by the force of the arc and deposited into the molten pool of base metal, as filler material, resulting in a thoroughly fused joint. (See fig. 38.)

(2) In carbon arc welding a carbon rod is substituted for the metal electrode used in the metallic arc process. The arc is formed in the same manner and filler material is added as in the case of gas welding. Although not as common as the metallic arc process, this method has many applications in automatic welding machines.

c. A continuous supply of electrical current is required for arc welding and must be of a definite amount and voltage. Either direct or alternating current may be used.

(1) In direct current welding machines, the current flow is maintained in the same direction which results in the work and electrode being of opposite polarity. When the work is made positive and the electrode negative, the arrangement is termed "straight polarity" while

"reversed polarity" indicates that the opposite is true. The machine may be reversed at will to produce either polarity, and selection is usually determined by the type of electrode that is to be used.

(2) When an alternating current machine is used for welding, the polarity of the machine reverses with each alternation of the current, and special electrodes must be used to produce satisfactory results. The arc is made in exactly the same manner as in the direct current machine although this arc is also reversed in direction at each alternation of the current.

31. Types of machines.—As previously mentioned, arc welders may be classed as direct or alternating current machines. The common types of each are discussed in the following paragraphs along with general information on their proper maintenance.

a. Direct current machines.—A direct current welder consists of a heavy duty direct current generator driven by a suitable type of motive power. The voltage of such a generator will usually range from 15 to 45 volts across the arc although any setting is subjected to constant variation due to changes in the arc conditions. A fairly wide range of current output is necessary to accommodate the various classes of work; the range of current output will vary, depending upon the type of unit. In most direct current welders, the generator is of a variable voltage type and is so arranged that the voltage automatically adjusts itself to the demands of the arc. However, this voltage may be manually set to the correct range by means of a rheostat mounted on the control panel. Amperage of the welding current is also manually adjustable and is usually set to the proper range by means of a selector switch or series of plug receptacles. In either case, the desired amperage is obtained by tapping into the field coils of the generator at different points to increase or decrease its strength. When both voltage and amperage of the welder are adjustable by means of the controls described above, the machine is referred to as a dual-control type. Another system employed to a certain extent in the manufacture of welding machines makes use of adjustable generator brushes for the control of the current. In this case only one control is provided and both the amperage and voltage are varied proportionately by the movement of the brush assembly.

(1) When a power supply is available, welding generators are generally driven by means of an electric motor. The motor may be arranged to drive the generator through a flexible coupling although many units have the armatures of both the generator and

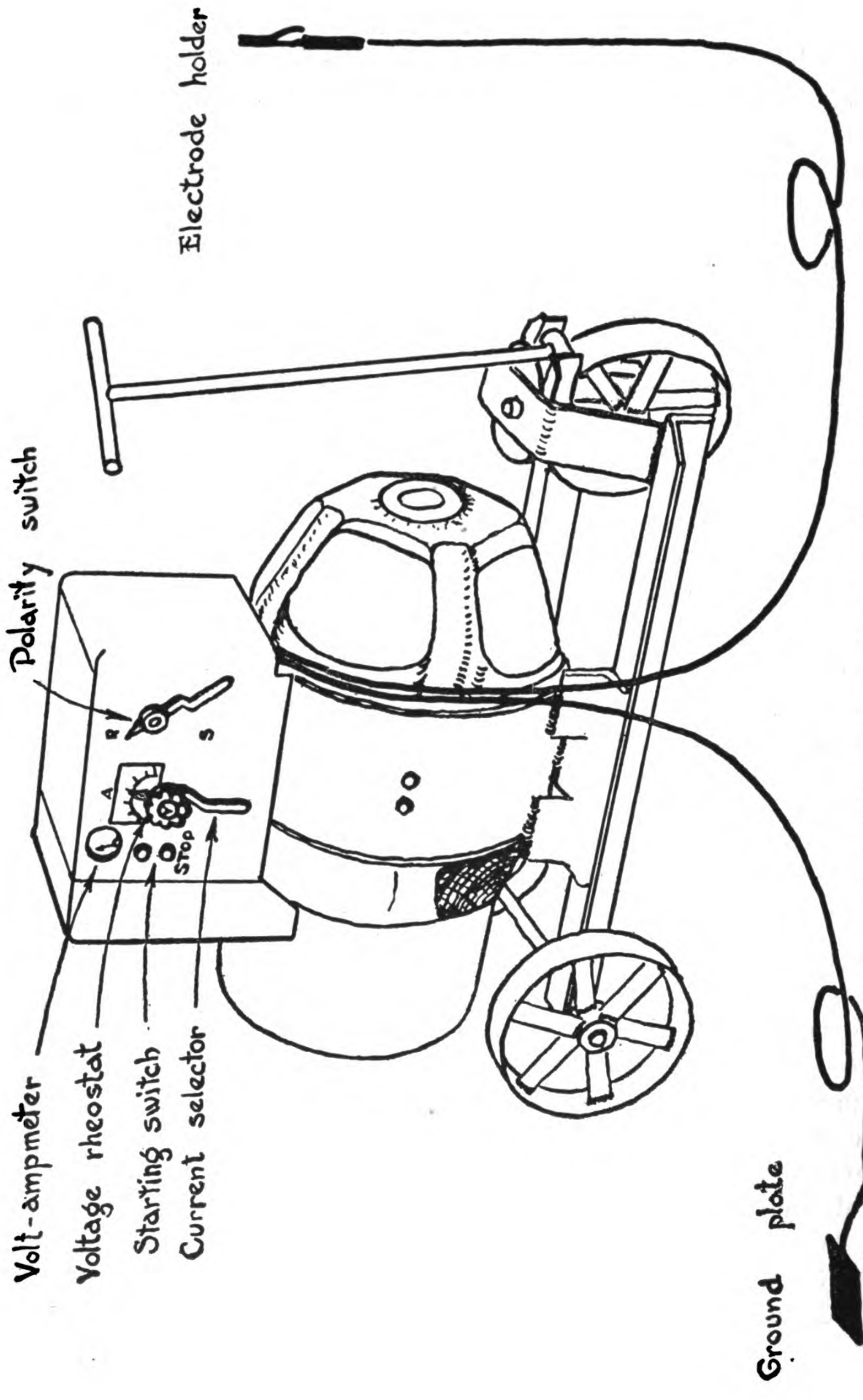


FIGURE 39.—Direct current motor-generator arc welding machine.

motor on a common shaft. Figure 39 shows a typical motor-generator welding machine of the dual-control type. In this figure the ground plate is attached to the work to be welded and the metal or carbon electrode clamped in the electrode holder.

(2) In many instances, arc welding must be performed in places where a power supply is not available. Portable gasoline engine-driven generators are particularly adaptable in such instances, as they are available in compact units that may easily be transported from place to place. The engine used for this purpose must be

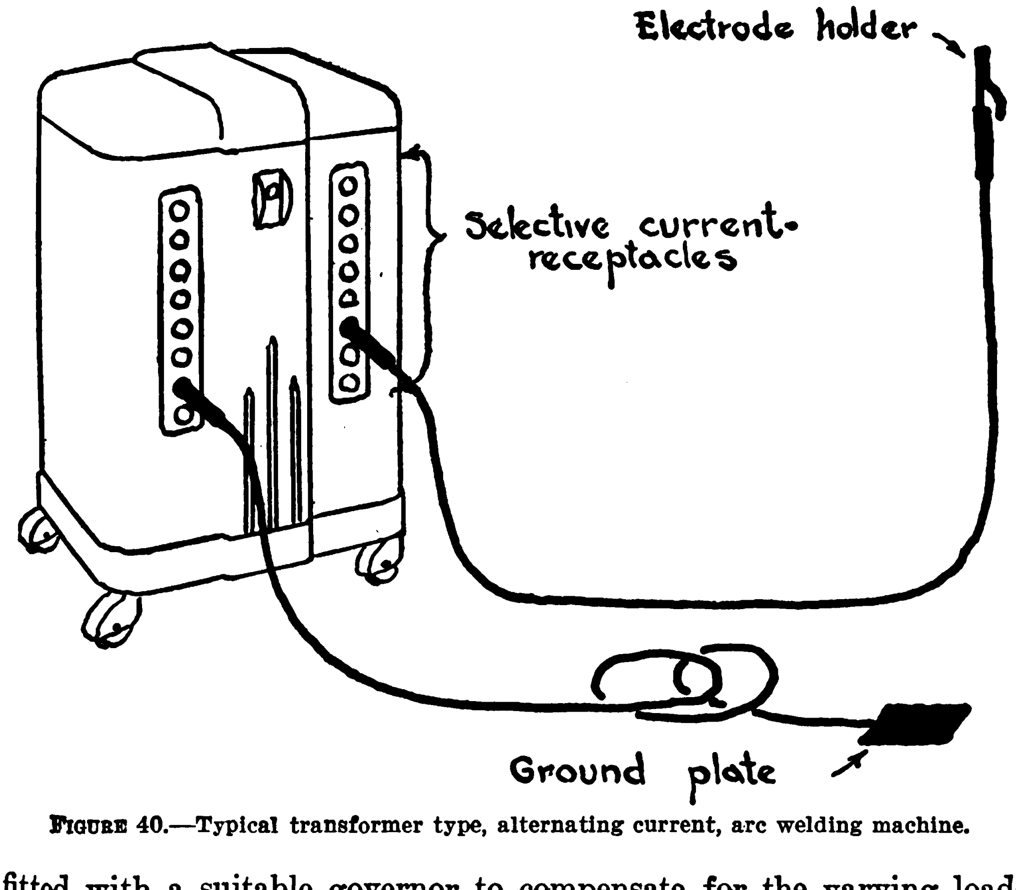


FIGURE 40.—Typical transformer type, alternating current, arc welding machine.

fitted with a suitable governor to compensate for the varying loads imposed by the welder.

b. Alternating current welders.—Alternating current welding machines may be divided into two general classes, the transformer type and the motor-generator type.

(1) The transformer type of alternating current welder derives its welding current from a closed core transformer. The primary coil of this transformer is hooked directly to the power line and the secondary coil is tapped at intervals for varying the welding current strength. A machine of this type is shown in figure 40 and the secondary taps may be seen on its front panel.

(2) The motor-generator type of alternating current welder is shown in figure 41. The welding current is supplied by a high frequency generator equipped with a two-position switch which allows the output to be changed from a high to a low value. An auxiliary control is also provided for fine current adjustment.

(3) Alternating current welders require the use of heavily coated electrodes and with this exception are practically as adaptable as the direct current machines.

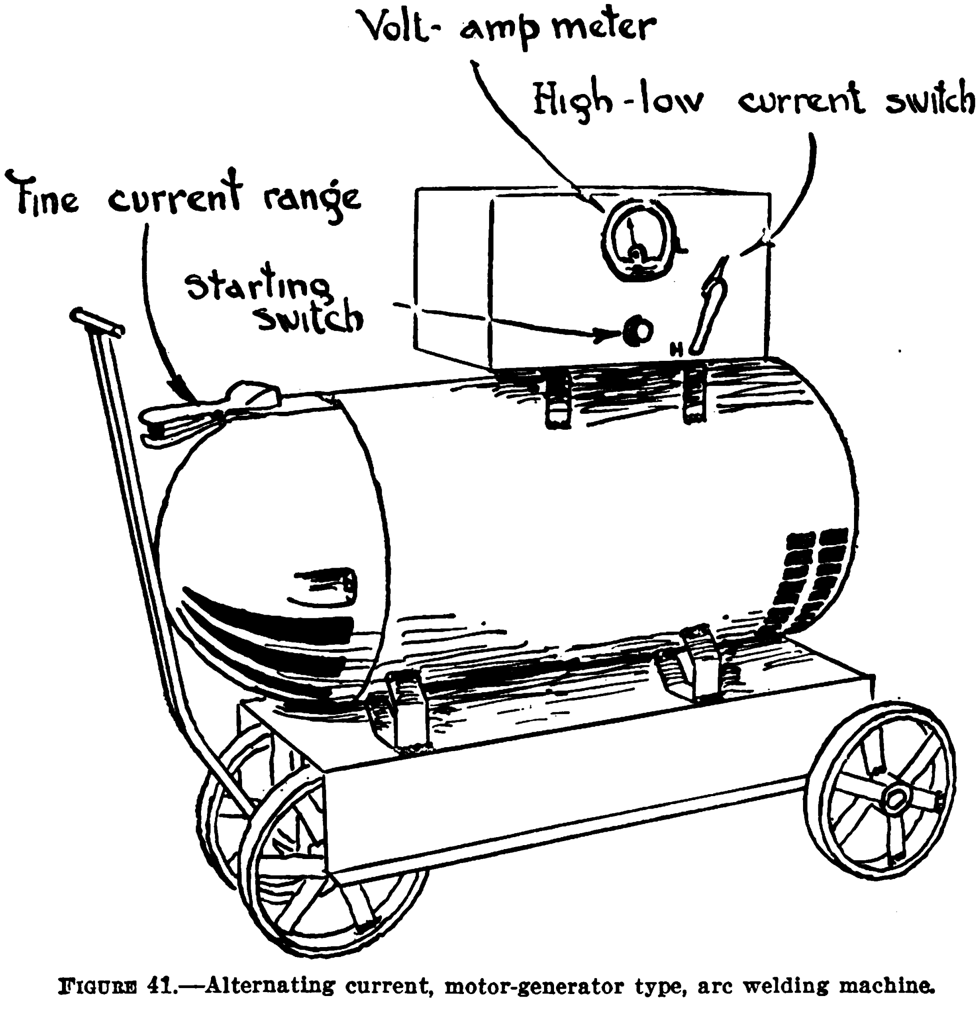


FIGURE 41.—Alternating current, motor-generator type, arc welding machine.

c. Maintenance.—Due to the amount of dust and grit that is present in all welding shops the problem of proper maintenance is a very important one. The following instructions will apply to most arc welding machines:

(1) Forced draft is used to cool most welding machines, and due to this fact particles of dirt are carried throughout the machine. Under average conditions, the unit should be given a cleaning with clean,

dry, compressed air at least once each month. This may readily be done by removing the dust covers and shields. Should the machine appear greasy at the time of cleaning, it should be dismantled and thoroughly washed with a mixture of carbon tetrachloride and naphtha. During the regular monthly cleaning, an inspection should be made of the condition of the switch points, brushes, commutator, and bearings.

(2) The machine should be given a thorough greasing at 4 to 6 month intervals. This may follow the cleaning operation and should include all bearings in the unit. Too much grease may be as harmful as not enough, as a surplus may be thrown upon the commutator, resulting in serious trouble. To grease properly a bearing of the type used in welding machines, the drain plug should be removed on the lower side of the bearing boss and the machine started. Grease may then be injected into the fitting until it begins to emerge from the drain plug hole. After allowing the machine to run for several minutes to force out any pressure on the grease, it may be shut off and the plug replaced. Only an approved grease should be used for this purpose.

(3) The brushes and commutators of both the motor and generator are subject to considerable wear. Brushes that have worn enough to reduce their spring tension appreciably must be replaced to maintain proper efficiency of the machine. Although new brushes are formed to fit the commutator, they must often be sanded in to give the proper amount of contact. This may be done by wrapping a strip of No. 00 sandpaper around the commutator with the rough side out and turning the armature by hand until the brushes have been worked down to a perfect fit. Brush springs that have become weakened from overheating should also be replaced to assure positive brush contact. Each time brushes are replaced the commutator should be checked for cleanliness and wear. If a deposit of graphite from the brushes is found, it may be removed by holding a piece of No. 00 sandpaper against the commutator while the armature is in motion as shown in figure 42. Ridges or pockets on the surface of the commutator will require the removal of the armature so that it may be trued up on a lathe. Only a light cut should be taken, and the mica separators between the bars of the commutator must be undercut from $\frac{1}{64}$ inch to $\frac{1}{32}$ inch after the truing operation. Although a special cutter should be used for this purpose a hacksaw blade will serve in an emergency. All electrical switch contacts should be sanded clean if pitted. Parts that have been badly burned should be replaced. At least once each year the windings of generator and motor should be inspected and if found dry or cracked given a coat of shellac.

32. Electrodes.—*a.* As previously stated the electrode may be either metal or carbon, and its selection is governed by the work to be welded as well as the requirements of the particular application. Metallic rods are available in a variety of metals and their alloys,

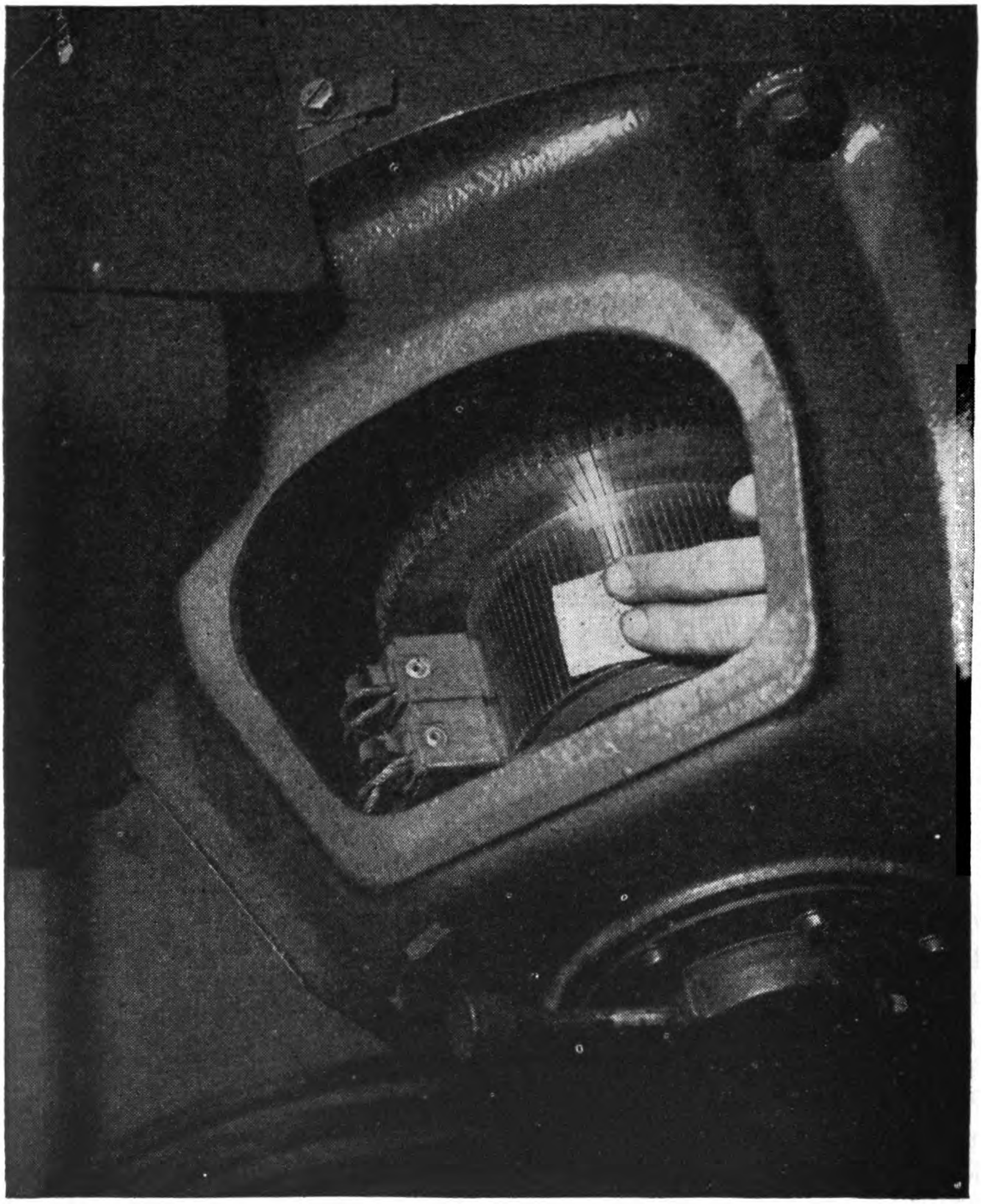


FIGURE 42.—Procedure for cleaning commutators.

making careful identification and selection necessary. Metallic rods may also be classed as to their coatings in the following manner:

(1) Washed electrodes are those which have been dipped or lightly coated with powdered lime or other similar substances. This thin

washed coating tends to stabilize the arc somewhat and in no way affects the deposit of weld metal. The use of an electrode of this type is illustrated in figure 38.

(2) Semicoated electrodes are those which have a coating of flux of appreciable thickness. This flux is mixed with a suitable binder and applied by dipping. The coating serves to stabilize the arc as well as partially control the oxidation of the weld metal by causing a thin deposit to be formed over the bead.

(3) Heavily coated shielded arc electrodes are those which utilize all the benefits of a chemical coating. The coating on this type of rod often amounts to 10 percent or more of the weight of the electrode and may be applied by winding, dipping, or extrusion. These coatings are such that they help to control the penetration, fluidity, shape of bead, and physical properties of the deposit. By the addi-

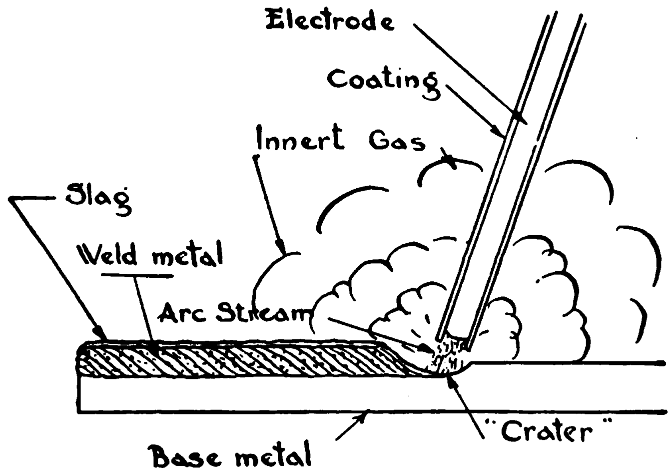


FIGURE 43.—Arc produced with a shielded electrode.

tion of various elements, the chemical composition of the weld metal may also be changed. An interesting and valuable feature of this type of electrode is the presence of the gaseous shield that protects the molten metal, preventing the formation of oxides and nitrides. The use of the heavily coated electrode is shown in figure 43.

b. Metallic electrodes are available for practically any type of welding requirement. The length is either 6 or 18 inches with diameters ranging from $\frac{1}{16}$ to $\frac{3}{8}$ inch.

(1) Welding rods are manufactured in all grades of mild, high carbon, and special alloy steel and are used for welding corresponding grades of steel. Special steel alloy rods are also made for welding cast iron.

(2) Cast electrodes are manufactured for use in welding iron and aluminum castings.

(3) Various other metals, such as aluminum and aluminum alloy, phosphor bronze, deoxidized copper, stainless steel, Inconel, etc., are available as electrodes for welding operations of a more or less special nature.

c. The polarity of the electrode is a very important consideration when welding with a direct current machine. Improper selection of polarity will greatly affect the speed of welding, depth of penetration, amount of splatter, etc.

(1) The positive side of a direct current welding circuit generates slightly more heat than the negative side. In welding with bare or lightly coated electrodes, the base metal requires more heat than the rod for proper fusion and is, therefore, made the positive terminal. As previously stated, this condition is referred to as straight polarity.

(2) Heavily coated electrodes are obtainable for welding the common steels which require reverse polarity for one type of coating and straight polarity for another type. There are electrodes available which perform satisfactorily with either polarity. In general, those used for welding the nonferrous metals require reverse polarity.

d. Alternating current electrodes must be of a bipolar type as the polarity is reversed at each reversal of the current flow. Should a rod be used that is designed for a definite polarity, excessive splattering will result and the deposit may have poor penetration.

e. Carbon electrodes have a standard length of 12 inches and are available in diameters from $\frac{5}{32}$ to 1 inch. In addition to their use in welding, the carbon electrodes are particularly valuable in cutting operations performed with a high amperage arc.

33. Welding technique.—As an arc is formed between the work and the electrode, a molten pool is immediately formed in the base metal. A crater or depression is made by the force of the arc and serves as an indication of the depth of penetration. Excessive voltage and current in the welding circuit will develop a deep crater and result in holes being burned through the metal if the work is thin. The welding arcs shown in figures 38 and 43 show this crater in its correct proportions, which in general practice should never be less than $\frac{1}{16}$ inch penetration into the base metal.

a. Striking the arc.—(1) The weld is started by striking or drawing an arc. Before this is done, the machine should be carefully adjusted to the proper setting for the work and the face protected with a mask or helmet. Care must also be taken to see that a good contact has been made between the work and the ground plate. The arc may then be struck by lightly dropping the electrode onto the

work and immediately raising it, drawing the arc to a distance approximately equal to the diameter of the rod. The electrode may then be moved to the point to be joined and the weld started. As the electrode burns away, the rod must be gradually lowered to maintain a constant length of arc.

(2) The arc length is the distance indicated in figure 38 and is measured from the end of the electrode to the surface of the molten metal. The arc length is kept as nearly as possible equal to the diameter of the electrode, except that the arc length is held at approximately $\frac{3}{16}$ inch with electrodes larger in diameter than $\frac{3}{16}$ inch. The arc length of the shielded or heavily coated electrode will appear slightly shorter than the arc length of the bare electrode because of the slower burning rate of the coating.

b. Weld movement and bead formation.—The speed of the weld movement depends to a great extent upon the proportions of the bead desired although current values also have a considerable effect. (See fig. 44.)

(1) If the travel of the weld is too fast, a flat, shallow bead (D) will result. If the rate of travel is too slow a high bead (E) will result. The bead (F) is the result of correct movement.

(2) When the current setting is too high, a flat, splattered bead (A) will be produced regardless of speed of travel. A setting which is too low will produce a small bead that lacks penetration as shown in (B). The bead (C) represents a weld using the correct current setting.

c. Arc blow.—The arc stream will often tend to shift from the joint or path of the weld. This tendency is referred to as arc blow and may cause considerable welding trouble. Arc blow is the result of a magnetic action set up by the welding current and may often be overcome by changing the direction of the weld or position of the electrode. A change in the position of the work may also improve the condition.

d. Cleaning and preparing work for welding.—As in the case of all gas welding operations, the work should be thoroughly cleaned of all scale, rust, and other foreign material before the weld is begun.

e. Regulation of welding current and voltage.—The largest factor governing the required welding current is the size of the electrode to be used. As the size of the electrode is increased, the amount of heat must also be greater. The amperage flow may be considered as giving the heat to the weld, and as it is increased the voltage must be increased. The amperage used for any welding operation is dependent upon the cross-sectional area of the tip of the electrode, and the kind and thickness of the metal. Regulation may be set by reference to the ammeter and voltmeter mounted on the control panel of most weld-

ing machines, and the following table gives approximate settings for all common conditions:

TABLE VIII.—*Voltage and amperage for various electrodes*

Electrode			Amperage and voltage setting					
Diameter (inch)	Metal	Coating	Flat position		Vertical position		Overhead position	
			Volts	Amperes	Volts	Amperes	Volts	Amperes
3/32	Steel	Washed	17–20	75–85				
1/8	do	do	19–20	90–115				
3/16	do	do	20–25	135–150				
3/32	do	Shielded	20–22	60–75				
1/8	do	do	25–26	90–120	25–27	65–75	22–24	75–80
5/32	do	do	24–26	90–135	26–28	75–100	26–28	90–100
3/16	do	do	24–30	100–175	28–30	100–130	30–35	100–125
3/32	Stainless steel.	do	25	60				
3/32	Inconel	do	24	50				
1/4	Cast iron	Washed	20	150				

f. Welding positions.—Arc welding positions are similar to the gas welding positions previously described.

(1) The flat or horizontal position should be used wherever possible as welding in this manner gives the operator a considerable advantage. Any weld made in a plane inclined at less than 45° to the horizontal is classed as a flat weld.

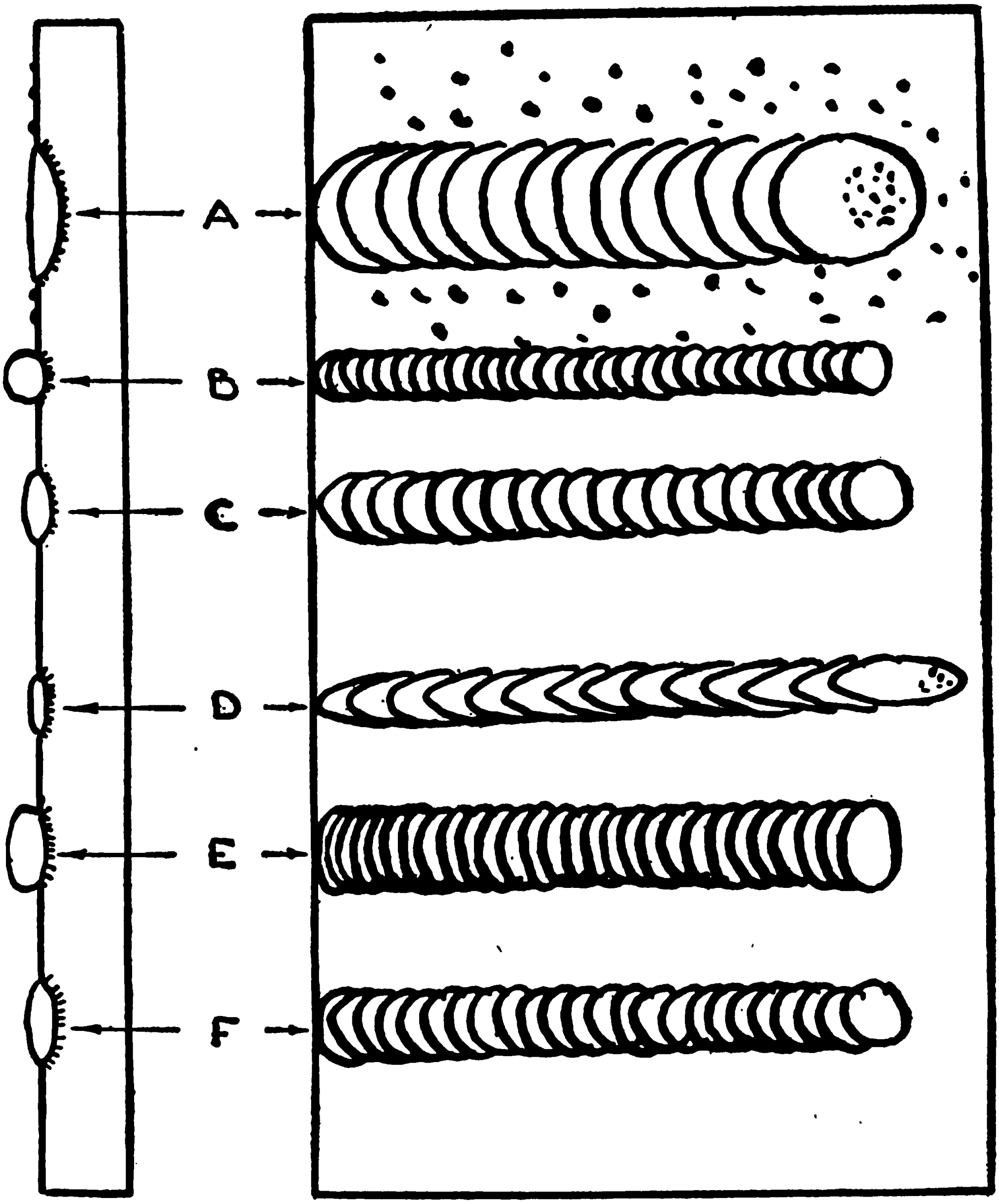
(2) The vertical weld is one having its linear direction inclined at more than 45° to the horizontal. Welds made in this position should always progress upward in order to allow for proper penetration.

(3) The overhead weld is the same as the flat weld except that the positions are reversed and the bead made from the under side. Overhead welding requires a lower welding current than welds made in the flat position, and progress must be slow to allow the metal to solidify.

g. Types of joints.—The joints used in arc welding are similar to those made by means of the oxyacetylene process. Preparation for welding is discussed in a later section, and the standard joints generally used may be described as follows:

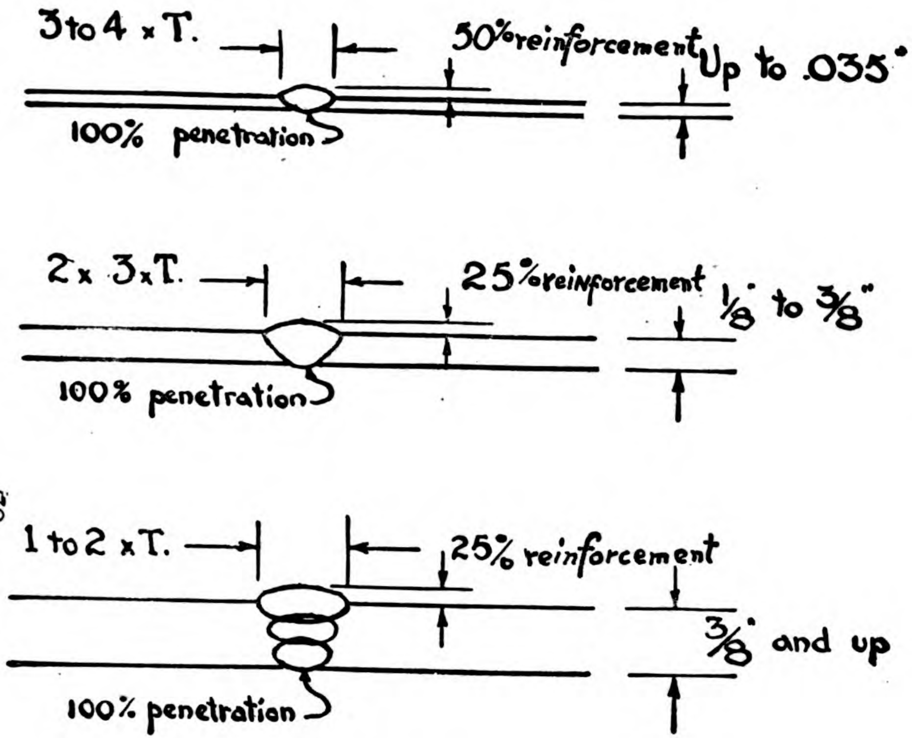
(1) *Butt joint.*—The butt joint (fig. 45) has many applications in all thicknesses of metal.

(*a*) When using bare or thinly coated electrodes, the bead may be built up to the required height by successive passes over the work. These passes should be straight welds, as the bare electrodes do not flow readily enough to allow any considerable amount of manipula-

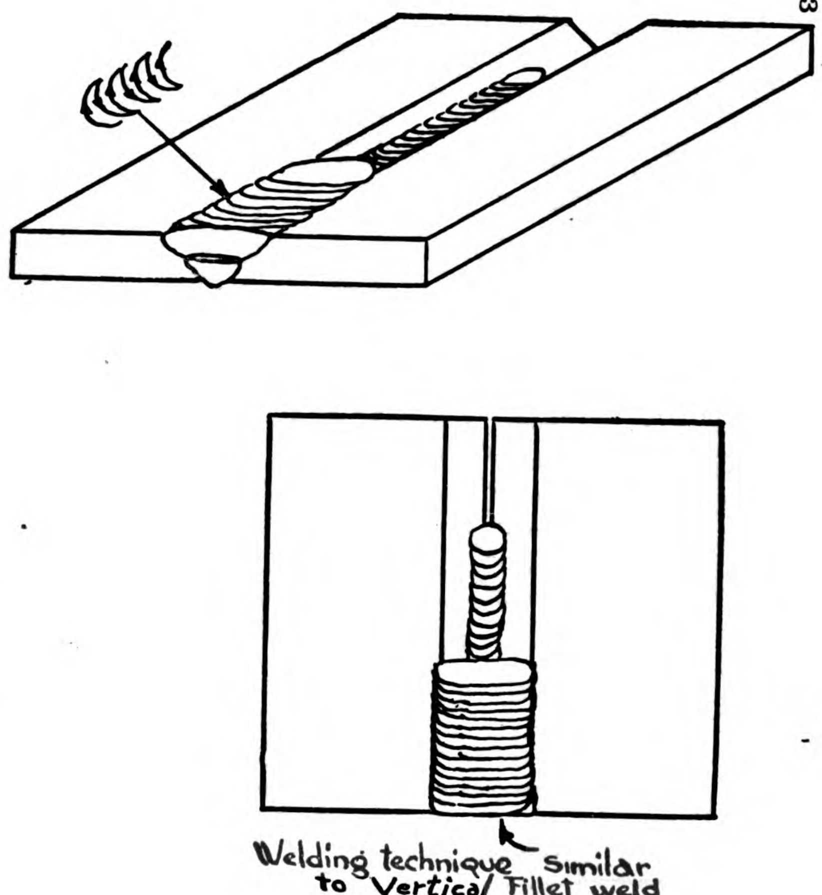


A. Current setting too high.
B. Current setting too low.
C. Correct current setting.
D. Rate of travel too fast.
E. Rate of travel too slow.
F. Correct rate of travel.

FIGURE 44.—Results of various welding speeds and current values.



① Proportions.

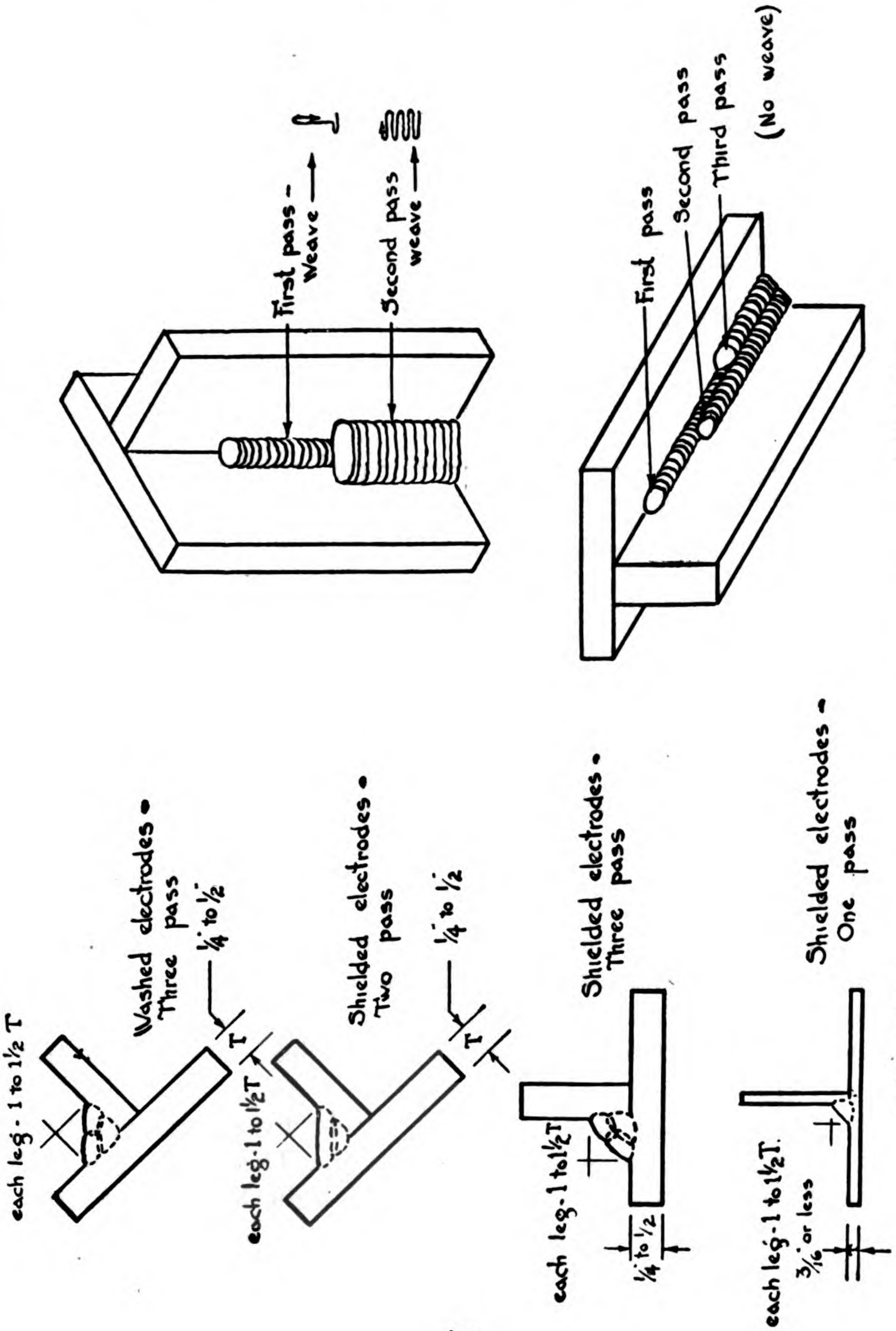


② Procedure.

FIGURE 45.—Butt joint.

tion. If more than two successive passes are required, the bead should be peened with a hammer after each successive layer to lessen distortion and stress.

(*b*) When heavily coated electrodes are used, the bead may be woven or manipulated in such a manner as to make additional passes unnecessary. This weaving may be a semicircular movement of the



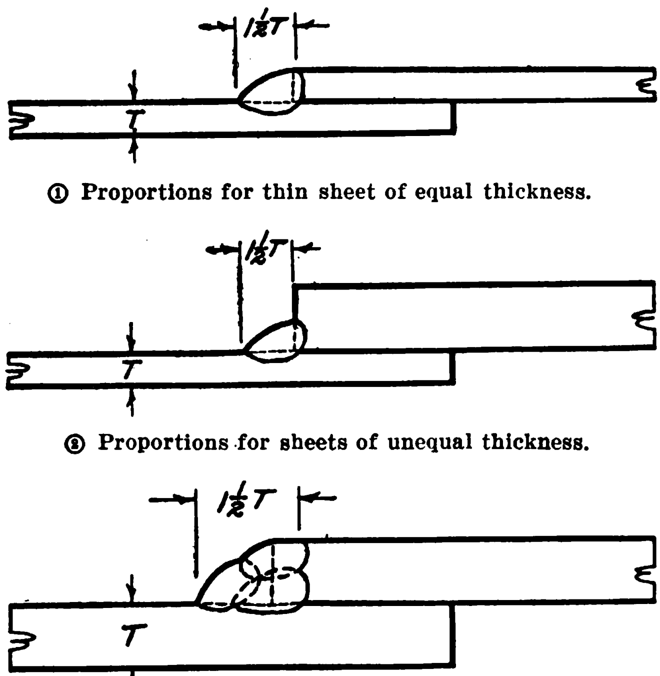
① Proportions. ② Procedure.

FIGURE 46.—Fillet weld tee joint.

electrode with the forward motion reduced until the desired filler has been deposited.

(2) *Fillet weld tee joint.*—This joint is shown in figure 46. Either bare or heavily shielded electrodes may be used and, in general, the recommendations are the same as for the butt joint. In using the shielded rod a straight bead should be made first, and if another layer is necessary the electrode may be manipulated to build up the required height.

(3) *Fillet weld lap joint.*—This type of joint is used to a great extent and lends itself readily to welding with either type of elec-



① Proportions for thin sheet of equal thickness.

② Proportions for sheets of unequal thickness.

③ Application of weld metal for heavy sheet and plate.

FIGURE 47.—Fillet weld lap joint.

trode. (See fig. 47.) Application of the electrode is made in a manner similar to that described for the tee weld.

34. Safety precautions.—In addition to the protective eye shield previously described for arc welding, other precautions are necessary to protect the skin from the strong ultraviolet and infrared rays produced by the arc.

a. The operator should be clothed entirely by a material heavy enough to keep these rays from penetrating. The hands should be protected by gauntlet gloves, preferably of light leather. A heavy apron made of leather or asbestos should be worn both for protection

against rays and drops of molten metal. For overhead welding, etc., one arm sleevelets and full leg spats are often required.

b. The inside of the welding booth should be painted a dull, flat color to help absorb the harmful light rays, and workmen employed in the vicinity of the arc welding operation should be provided with colored glasses for protection against reflection and occasional exposed flashes.

Section IV

ELECTRIC RESISTANCE WELDING

35. General.—Resistance welding is a process whereby a low voltage, high amperage current is brought to the work through a heavy copper conductor offering very little resistance to its flow. The work placed in the path of the current flow sets up a great resistance to it, and the heat generated by this resistance is sufficient to fuse the parts together at their point of contact. Most resistance welding machines

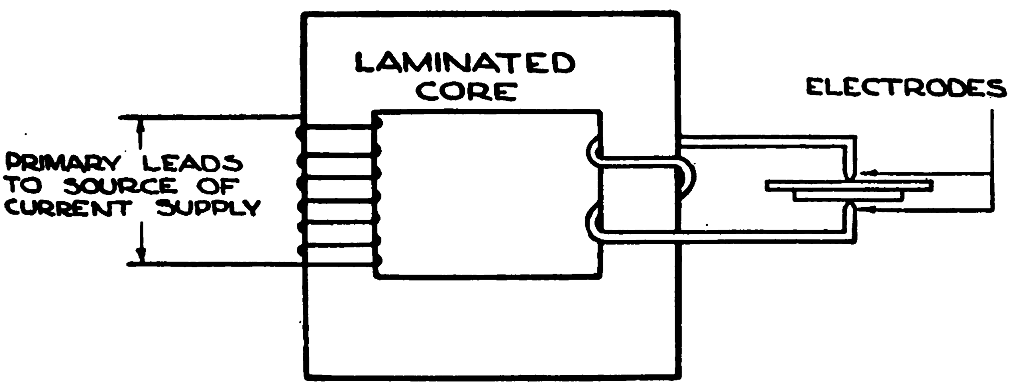


Figure 48.—Schematic diagram of a typical resistance welder.

are simply alternating current, single phase transformers, having a secondary coil of one or two turns. Both the primary and secondary coils of the transformer are wound on a heavy core or frame, and the leads from the high amperage or secondary side are connected to clamping jaws that are brought together upon the work to be welded. (See fig. 48.)

36. Types of resistance welders.—Resistance welding is particularly adapted to duplicate or production work and is employed to a considerable extent in the aircraft industry. Several forms are in common use and may be described as follows:

a. Butt welding machine.—The butt welding process consists of joining pieces end to end. The welding current flows through the

parts to be joined and encounters its highest resistance at their point of contact. The heat generated is sufficient to produce complete fusion of the cross section, making a sound weld. The butt welding machine is a simple device composed of a suitable transformer whose high amperage leads terminate in a pair of jaws. One of these jaws is stationary while the other is movable by means of a lever. Both jaws have clamping ends to which the pieces to be welded may be attached. When the work is clamped in place, the circuit is closed and the lever moved to bring their butt ends together.

b. Spot welding machine.—Spot welding is similar to butt welding and consists of passing the welding current through the plates or sheets to be joined at the "spot" or point of electrode contact. The electrodes are made of hard copper or of a copper alloy which is harder than ordinary copper and slightly lower in electrical conductivity. Spot welding is particularly adaptable to thin sheet metal construction and has many applications in this type of work. Figure 49 shows a typical spot welding machine. The electrode jaws are extended in such a manner as to allow a weld to be made a considerable distance from the edge of the sheet. The copper electrodes terminate in blunt end die points which concentrate the heat in a small area. A pedal trip or release is generally used to regulate the movement of the jaws and its action may be manually controlled. A control is also provided for current regulation.

c. Flash welding machine.—In flash welding, the fusing of the parts is accomplished in three steps. The metals to be joined are first subjected to a light pressure between the electrodes, then separated very slightly to allow arcing to occur. The small arc brings the metals to their melting points at the separated edges, and as a final operation the parts are forced together by means of heavy pressure. As they meet, the molten metal and oxides are thrown out and a clean fusion results. The flash welding machine is similar in construction to other resistance welders. The electrode arms must, however, be made to hold the parts to be welded rigidly and have provision for their accurate separation.

d. Portable gun welder.—The portable gun welder is a form of spot welder which may be moved to the work. The name "gun" comes from the resemblance of the mechanism, which carries the electrodes, to a riveting gun, and from the fact that the mechanism may be transported and operated in much the same manner as the riveting gun. The control panel and transformer are sometimes suspended from an overhead rail. Water-cooled cables carry the welding current to the gun. The

pieces to be welded are clamped between the electrodes by means of either hydraulic or air pressure. The pressure, welding time, and current are preselected by the operator, and he then only needs to press the gun trigger to start the welding operation.

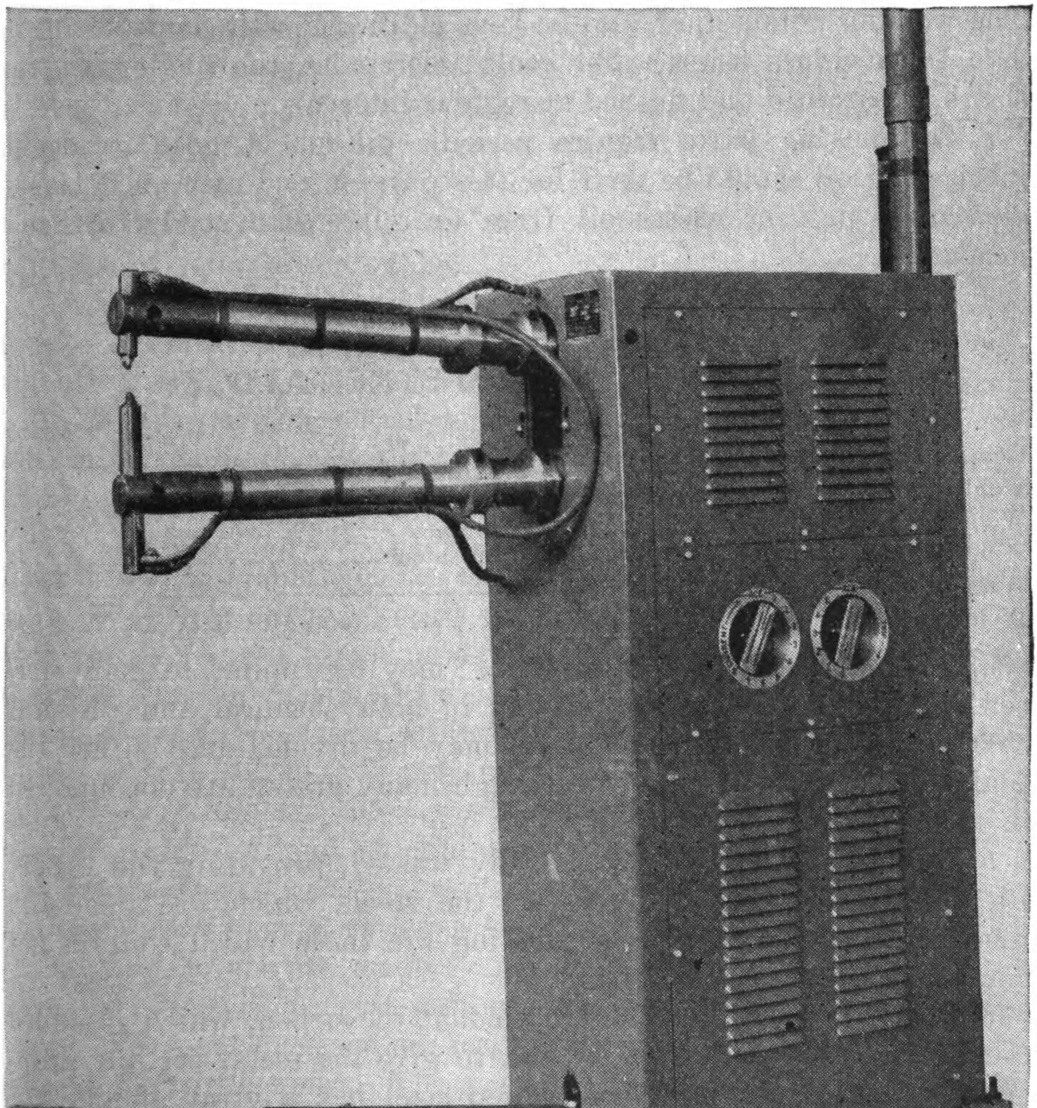


FIGURE 49.—Electric resistance spot welder.

37. Maintenance of resistance welders.—Resistance welding machines cannot work at their best unless kept in good condition by regular inspection and repair.

a. All electrical connections must be kept clean and tight to keep line resistance at its minimum and maintain proper heating efficiency. The welding points must also be kept clean and well shaped.

b. In machines using water cooled electrodes, the cooling system should be drained and flushed at regular intervals.

c. All moving parts require periodic oiling. A good grade of lubricating oil should be used for this purpose and care must be exercised to prevent excess oil from draining onto conductors and insulation.

SECTION V

WELDING STEEL AND STEEL ALLOYS

38. General.—*a.* The term "steel" may be applied to many ferrous mixtures which differ greatly in both chemical and physical characteristics. In general, steels may be divided into either the plain carbon or alloy groups although many grades are encountered in each of these classifications.

b. Most steels may be successfully welded, providing the proper procedure is employed; however, the steels which are generally used for parts fabricated by welding are those which contain not more than 0.30 percent carbon.

(1) All steels have a definite amount of carbon, which is added during the manufacturing process, to give the metal certain properties. Due to the fact that molten steel has a great affinity for carbon, extreme care must be exercised during all welding processes to avoid change in its content.

(2) Oxygen is destructive to steel as it combines with the metal to form iron oxides. When steel is melted in an oxidizing atmosphere, these oxides are greatly increased and are usually distributed throughout the metal which has been melted.

(3) Nitrogen from the atmosphere will combine with melting steel to form nitrides of iron, and when incorporated in the metal to any great amount will produce low strength properties.

c. The inclusion of impurities may be held to a minimum by careful welding procedure, and the following points should be observed when welding with the oxyacetylene flame.

(1) A well-balanced neutral flame is satisfactory for all steels, although a very slight excess of acetylene may be used for welding alloys of a high chromium or nickel content.

(2) The volume of flame used should be sufficient to reduce the metal fully to the molten state and permit proper penetration for the type of joint being welded.

(3) Excessive pressure of the gases should be avoided as this gives a harsh flame making it difficult to control the melting metal and often results in cold shuts or laps.

(4) The tip of the central cone should be held slightly above the surface of the work and the flame so manipulated that the melting metal is protected by the envelope or outer flame.

(5) The hot end of the welding rod should always be kept within the limits of the puddle or the enveloping flame.

39. Welding carbon steels.—The carbon steels are divided into four classes: Low carbon, mild carbon, medium carbon, and high carbon. The low carbon series have a carbon content of 0.07 to 0.20 percent; the mild carbon series, 0.20 to 0.30 percent; the medium carbon series, 0.35 to 0.45 percent and the high carbon series, 0.50 to 2.00 percent. In these steels, carbon determines the tensile strength, ductility, and weldability of the metal.

a. Low carbon steels.—These steels are very common in the industrial field and have a variety of uses. Wire, nails, drawn tubing, chains, and rivets are made from steel with a carbon content of from 0.05 to 0.10 percent, while boiler plates and tubes, screws, rivets, and some forgings are made from steel having a 0.10 to 0.20 percent carbon content. These steels are workable in the hot or cold state to any form desirable. They do not harden upon sudden cooling from a high temperature and are weldable by all methods. The strength of welds properly made in these steels is equal to or greater than the strength of the base metal when in a hot rolled or drawn condition.

b. Mild carbon steels.—These steels are obtainable in bar, sheet, and tube form in the cold rolled condition. In the Army Air Forces this series of steel is used for ground equipment only, however, in some commercial aircraft it is used in the sheet form for moderately

stressed fittings and in the tubular form for some structural members. Mild carbon steel may be welded satisfactorily by all methods, although it requires more careful control of the flame and heat than the lower carbon series. The melting metal boils and sparks excessively when the volume of heat is in excess of that required for the metal being welded. It also scales badly when overheated, and the grain structure of the weld and adjacent base metal is made exceptionally large, resulting in low strength properties. Welds made with the electric arc, using shielded electrodes, have a strength equal to the base metal.

c. Medium carbon steels.—These steels are used in the bar form and are obtainable in the annealed, cold rolled, or normalized condition. They are used for general machining or forging purposes where high strength and surface hardness are essential. Although not generally used for parts fabricated by welding, they may be welded satisfactorily with the metallic arc if the procedure is carefully controlled. Cold rolled material should be normalized before welding, and the procedure must be such that heat strains will be minimized to prevent the weld or adjacent base metal from cracking. After welding, the part should be stress relieved. Metallic electrodes of the shielded type are preferable for arc welding all medium carbon steels.

d. High carbon steels.—The high carbon steels are obtainable in the bar, sheet, and wire forms in the annealed or normalized condition. The bar form is used for the manufacture of hand tools, such as chisels, drills, hammers, etc., which are to be heat-treated after fabrication. The sheet and wire forms are extensively used for springs. Tools made of this steel may be repaired by welding, in which case special welding rods are required. Springs cannot be satisfactorily welded as the cast metal of the weld will not stand up under flexing stresses even though the weld is heat-treated to the original degree of hardness. When welding the carbon steels by means of the oxyacetylene process, the flame must be carefully adjusted to neutral.

40. Welding chrome-molybdenum alloy steels.—*a.* Chrome-molybdenum alloy steel is extensively used for parts fabricated by welding. It is obtainable in the bar, sheet, and seamless tube forms. The sheet and tube forms are employed in aircraft construction for welded assemblies, such as steel tube fuselages, engine mounts, and landing gears. These forms are also used in the construction of fittings and brackets for the installation of auxiliary parts.

b. This steel welds satisfactorily by all methods and processes. The oxyacetylene flame is generally preferred for welding thin wall tubing and light gage sheet, particularly where the metal cannot be backed

up on the opposite side from which the weld is to be made. For material 0.093 inch thick and greater, the arc is preferred as the heat zone will be much narrower, resulting in lower heat strains. This is an advantage, especially when the part is too large to be heat-treated for the relieving of stresses built up by welding. The welding technique with the oxyacetylene flame is about the same as that required for the carbon steels, except that the surrounding area should be warmed to between 300° and 400° F. before starting the weld. This is necessary as a sudden application of the flame without some preliminary heating sometimes results in the formation of cracks in the heated area. The flame should be directed on the metal at such an angle that preheating takes place ahead of the weld. A soft, neutral flame must always be used as an oxidizing flame burns the steel and weakens it. A weld made with an oxidizing flame may crack on cooling if contraction is restrained. A carbonizing flame makes the metal brittle and will also cause cracking on cooling. The volume of flame should be just large enough to reduce the base metal to a melting state so that proper fusion will take place. Overheating will result in severe strains being set up and will cause excessive grain growth, which contributes to low strength in the welds and adjacent area of the base metal. The metal should be protected from the air as much as possible while hot, and welding in an atmosphere of hydrogen is recommended. This may be done by directing a jet of hydrogen directly on the metal from the side opposite the weld. The addition of hydrogen reduces scaling caused by oxidation and adds to the strength of the finished part by eliminating air hardening around the weld.

c. When jigs or fixtures are used they should be designed to prevent strains from contraction as the metal cools.

d. A welding rod containing 0.06 percent carbon, 0.15 percent manganese, and 0.06 percent silicon is used for general welding of this metal with the oxyacetylene flame. A chrome-molybdenum rod may be used for joints requiring high strength, provided the part can be heat-treated after welding. This rod contains about 0.30 percent carbon, 0.80 percent manganese, 0.25 percent molybdenum, and 1.0 percent chromium. For electric arc welding, the shielded type, straight polarity rod gives excellent results. This rod contains 0.10 to 0.18 percent carbon and 0.30 to 0.60 percent manganese.

e. The tensile strength of welded joints in light gage sheet and tubing made under proper conditions and using the carbon steel welding rods will be from 90,000 to 95,000 pounds per square inch without heat treatment. Proper heat treatment will raise the strength of the weld to from 130,000 to 135,000 pounds per square inch. When

the chrome-molybdenum rod is used and the weld is heat-treated, the tensile strength will be approximately 180,000 pounds per square inch.

41. Welding chrome-nickel corrosion resistant steels.—*a.* Chrome-nickel corrosion resistant steel, commonly referred to as stainless steel, contains 18 percent chromium and 8 percent nickel, with varying amounts of carbon, manganese, molybdenum, titanium, and columbium.

b. This metal is weldable by all processes, and welds made under proper conditions, with either the electric arc or oxyactetylene flame, will develop a tensile strength equivalent to the base metal in the annealed condition. Due to the heat required for welding, the corrosion resistant property will be reduced somewhat in the weld metal and adjacent base metal. This is the result of an increase of carbides in the heated area. If, after welding, the metal can be heated uniformly to a temperature of 1,900° to 2,000° F. and cooled quickly, these carbides can be put back into solution and the corrosion resistant property restored. An air quench is considered sufficiently rapid for thicknesses up to 0.0625 inch, while heavier gages will require a water quench to accomplish the desired effect. These steels have a melting point of 2,500° to 2,600° F. The coefficient of expansion is about 60 percent greater than the carbon steels, and the thermal conductivity is from one-third to one-half less than these steels.

c. Corrosion resistant steel oxidizes readily if heated with a flame containing an excess of oxygen. As oxides formed in this manner tend to prevent proper cohesion of the weld metal and base metal, careful attention must be given to the adjustment of the welding flame. A strictly neutral setting is preferable but is difficult to maintain with the average equipment, and the flame may change from the neutral to the oxidizing side without being noticed. A very slight excess of acetylene is therefore recommended in most cases. The feather or brushlike second cone, indicating an excess of acetylene, should not extend more than 1/16 inch beyond the tip of the central cone. If the flame contains more acetylene than is required, the hot metal will take up the free carbon resulting in a brittle weld. Any increase in carbon content will also reduce the corrosion resistance of the metal.

d. Corrosion resistant steel should be well protected from the air during welding to prevent the oxygen and nitrogen of the atmosphere from combining with the hot metal. Welding in an atmosphere of hydrogen or the direction of a hydrogen flame on the oppo-

site side of the seam from which the weld is being made provides the best kind of shield. If this method is not available, the metal must be protected with a suitable flux. For electric arc welding, the rod is coated with a flux which forms a gas that surrounds the hot metal while it is being deposited. This flux also deposits a slag on the weld metal that protects it until it cools. Flux used for oxyacetylene welding is obtainable in the powder form and is mixed in clean, cold water to form a creamlike paste. A film of the flux should be brushed on the under side of the joint and may also be applied to the rod. This flux when allowed to dry protects the metal that cannot be covered with the flame. When welding with the oxyacetylene flame, the rod should be kept within the limits of the flame envelope and added by allowing it to melt and flow into the melting puddle. Stirring or puddling the hot metal with the rod should be avoided.

e. The welding tip or nozzle should be in good condition in order to give a flame that does not fork or spread. The tip or nozzle may be one size smaller than is regularly used for a similar thickness of ordinary carbon steel.

f. When welding sheet stock, the sections should be held in a jig wherever possible in order to keep the edges in alinement and reduce the conduction of heat into the sheet. When a jig is used, it should not be clamped so tight that normal contraction will be restrained. After a weld has been started in this metal, it should be continued without interruption until the joint is completed. If for any reason the weld is stopped midway in a joint, it must not be restarted without first bringing the metal to a red heat for several inches. Either of the following methods may be satisfactorily used in the butt welding of sheets and plates:

(1) Set the work up with the edges separated a distance equal to the metal thickness and tack weld at regular intervals of 2 inches.

(2) Separate the edges so that the spacing is equal to the metal thickness at the starting point but gradually tapers out at the rate of 3/8 of an inch per foot of seam length.

42. Weld metal specifications.—The weld metal specifications for the various welds used in the construction of aircraft and fabricated of steel sheet and tubing have been standardized and may be described as follows:

a. The weld shown in figure 50 illustrates the requirements for a square edge butt joint in plain carbon or chrome-molybdenum steel sheet and tube up to 0.093 inch in thickness.

(1) The width of the fusion zone for metals exceeding 0.093 inch will be governed by the preparation of the joint. If the ends to be

welded are beveled to 45°, the weld should be about 1/8 inch wider than the included angle of the V. This will give a depth of fusion of 1/16 inch into the wall of the V on each side of the joint.

(2) The height of the reinforcement for metal thicknesses up to 0.0625 inch should be approximately equal to the metal cross section. This dimension may be reduced as the base metal thickness increases.

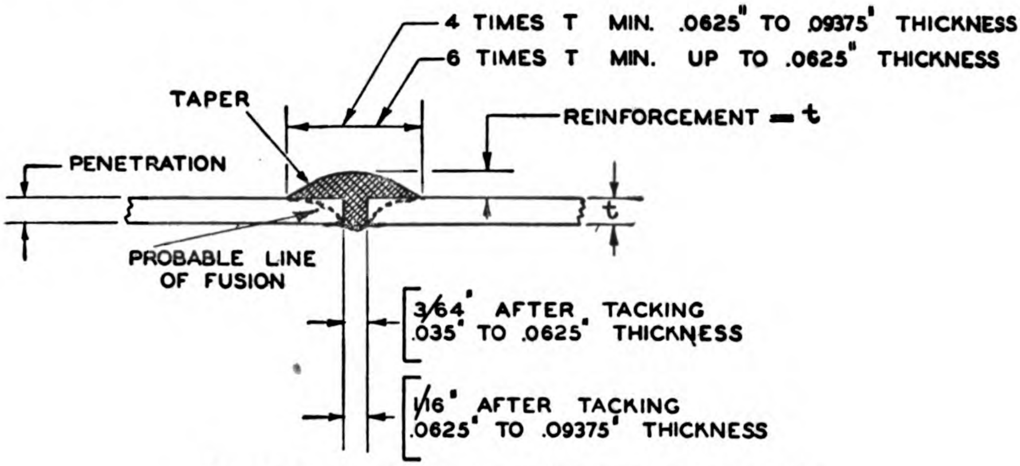


FIGURE 50.—Weld metal specifications for butt joints.

For thicknesses from 0.0625 to 0.093 inch the dimension of the weld through the throat should be about 75 percent greater than the base metal, while for metals from 0.093 inch to 0.125 inch this dimension may be 50 percent greater than the base metal. In stock that is thicker than 0.125 inch the bead need only be 25 to 30 percent of the base metal thickness. In all cases, this reinforcement must have an even contour and taper gradually to the base metal at the edges.

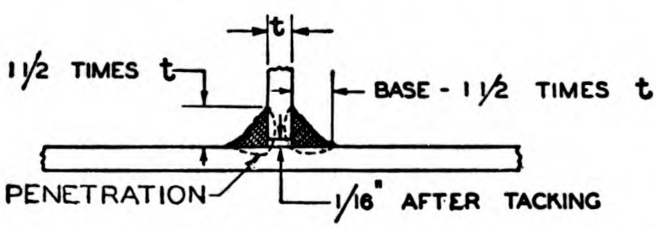


FIGURE 51.—Weld metal specifications for fillet tee and angle joints.

(3) Penetration for all thicknesses must be completely through the base metal at the joint. Excess weld metal on the side opposite from which the weld is made should be avoided.

b. Figure 51 shows the requirements for a fillet weld tee joint for sheet stock where the pieces in the joint are of equal thickness.

(1) Each leg of the weld metal should not be less than 1½ times the metal thickness.

(2) The thickness through the throat of the weld metal must not be less than the base metal and the face should be slightly concave.

(3) Fusion should penetrate into the root of the joint and base metal sufficiently to obtain good fusion, and the weld metal should taper gradually into the base metal at the toe of the weld.

c. Figure 52 shows the requirements of the weld metal in lap joint fillet welds.

(1) The width or length of the horizontal leg of the weld metal should not be less than 1½ times the base metal thickness.

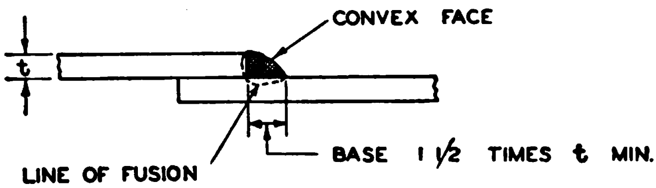


FIGURE 52.—Weld metal specifications for fillet lap joints.

(2) The depth of fusion must penetrate to the root of the joint and into the base metal sufficiently to obtain good fusion.

(3) The face of the weld metal should be slightly convex, and the weld metal must taper gradually into the base metal at the toe.

d. Figure 53 shows the requirements for an edge weld of two pieces of sheet stock. For thin gage sheet, the depth of fusion should be uniform and follow the dimensions given in the figure. In heavy gages these dimensions may be reduced 25 to 50 percent. A weld of this type must never be used to support heavy loads.

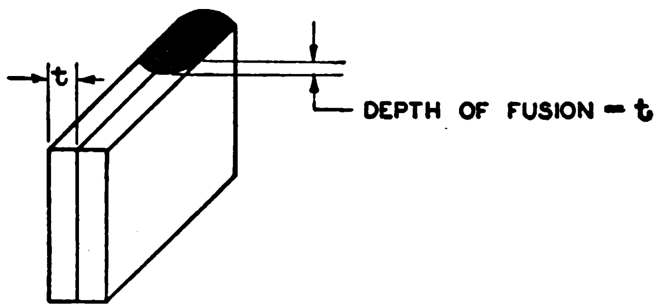


FIGURE 53.—Weld metal specifications for edge welds.

e. Figure 54 shows the requirements for a fillet weld tee joint between sheet and tubing, where the sheet stock has a greater thickness than the wall of the tube. It should be noted that the dimensions for the throat and base or leg of the weld metal at point (A) are based on the plate thickness, while the dimensions of the weld metal at point (B) are based on the tube wall thickness.

f. Figure 55 shows the weld metal requirements for tee and angle joints between sections of tubing such as are used in the manufacture of aircraft structural units.

(1) The weld metal at (A) and (B) should be of the same dimensions as the fillet weld tee joint previously described.

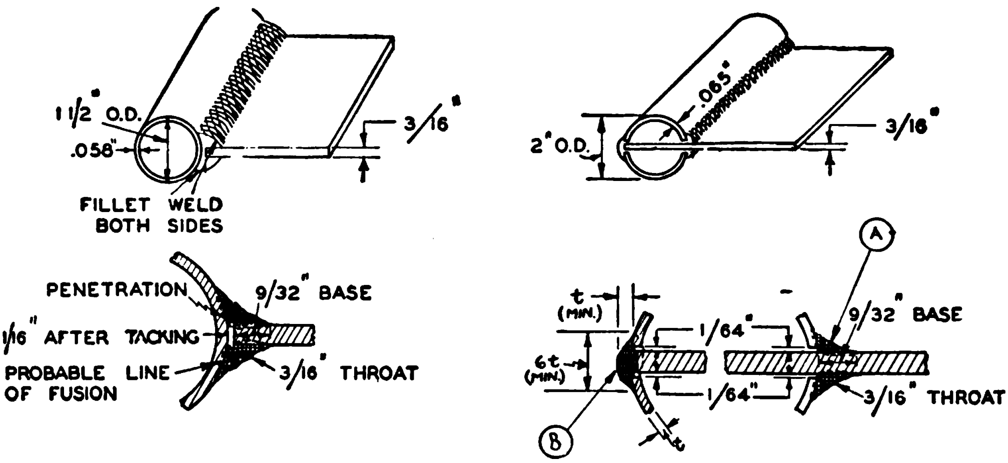


FIGURE 54.—Weld metal specifications for sheet and tube joints.

(2) The dimensions of the weld metal at (C), (D), and (E) should be the same as those of an ordinary butt weld.

(3) The depth of fusion into the base metal should penetrate to the points indicated in all thicknesses. It should be noted that the depth of fusion penetrates the wall of the tube at the joint but does not penetrate the full thickness of the member to which it is welded.

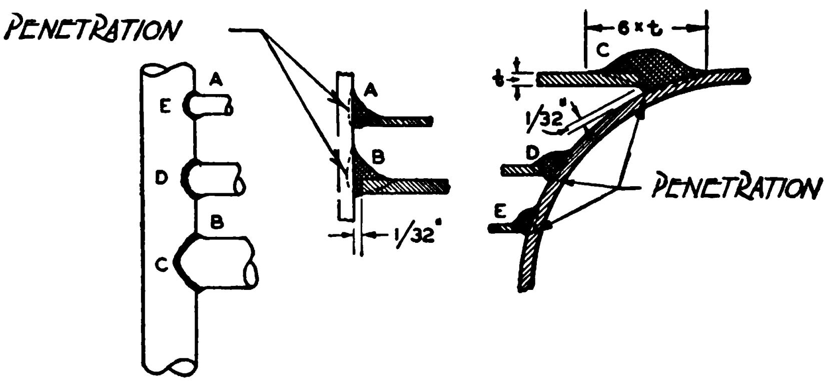


FIGURE 55.—Weld metal specifications for tubular angle joints.

g. In welding corrosion resistant steel alloy, the specifications of the weld metal may be modified as to width and amount of reinforcement. For butt joints the width of the fusion zone or weld metal need not be more than 4 times the metal thickness in stock up to 0.0625 inch in cross section. The thickness through the throat of

the weld should be about 1½ times the base metal thickness. Penetration and fusion of the base metal on each side of the joint are essentially the same as required for other steels.

h. The foregoing specifications for the different types of welds apply to the use of a blowpipe. The weld metal for the same types of joints made with the electric arc will deviate slightly in form and width but the depth of fusion must be the same.

43. Welding rods for steels.—*a*. The welding rod used for welding ferrous metals (iron and steel) with the electric arc are described in the section on electric welding.

b. Those used for gas welding are classified by grade for the type of work and metal for which they are to be used.

(1) Grade 1–G is a copper coated rod of low carbon content. It is used for general welding of the carbon and chrome-molybdenum alloy steels. This rod is obtainable in 1/16, 3/32, 1/8, and 3/16 inch diameters.

(2) Grade 2–G is a chrome-molybdenum rod used for welding chrome-molybdenum alloy steel parts that require heat treatment to obtain higher strength properties. This rod is obtainable in 1/16, 3/32, and 1/8 inch diameters.

(3) Grade 3–G is a chrome-nickel stainless steel rod used for welding the chrome-nickel corrosion steel alloys. It is obtainable in 1/16, 3/32, and 1/8 inch diameters.

c. The diameter of rod that should be used for the different classes of work depends largely upon the thickness of the metal being welded; however, the volume of metal and welding conditions must also be considered in its selection. The diameters of the rods used for average welding operations on plain carbon and chrome-molybdenum alloy steel are given in table IX. If the volume of metal being welded and the conditions under which the weld has to be made are such that a larger volume of heat is required, the rod diameter should be increased. If this is not done, the rod will melt too rapidly and is apt to cause poor fusion between the filler and base metals. If the rod is too large, it will not melt at the right time and will chill the pool of melting base metal. This condition will retard the welding and also cause poor fusion of the added metal with the base metal.

TABLE IX.—*Welding rod selection for the oxyacetylene process*

Metal thickness (inch)	Diameter of rod (inch)
Up to and including 1/16	1/16
1/16 to 1/8	3/32
1/8 to 3/16	1/8
3/16 to 1/4	5/32
1/4 to 3/8	3/16

d. When welding stainless steel, a 1/16-inch rod is usually used for metal thickness up to and including 0.045 inch, while heavier metals require rods of greater diameter.

SECTION VI

WELDING FERROUS CASTINGS

44. General.—*a.* Ferrous castings may be divided into five groups or classes: gray cast iron, white or chilled cast iron, malleable iron, semisteel, and steel castings. The metallic and chemical elements are present in varying percentages and exist in different forms in each of the groups. The content of the elements and the condition in which they exist determine the nature and physical characteristics in all cases. Because of these differences in characteristics, the kind of metal in the casting should always be determined before any welding is attempted.

b. The welding of castings is generally in the form of repair work as this material is subject to frequent breakage when overstressed. Steel and gray iron castings may be successfully welded by the fusion method, but in the case of malleable iron this method must not be used as the metal when melted becomes extremely weak and brittle.

c. Castings may be identified by grinding with an emery wheel or by chipping with a chisel.

(1) The characteristics and description of the spark stream produced by grinding are shown in figure 37. Semisteel is not shown in

the chart, but its spark characteristics are very much like those of malleable cast iron.

(2) When testing these metals to identify them by chipping with a chisel the steel castings of a low carbon content will cut easily and the chips will curl before breaking off. When chipping gray cast iron, the chips will break loose with each blow of the hammer. White or chilled cast iron is very hard and cannot be cut or chipped with a chisel. The chips from malleable cast iron are similar to those of steel on the outer surface, but when this surface has been penetrated, the chips break off in the same manner as gray cast iron. Semisteel chips form and break off similarly to the surface chips of malleable cast iron although the chips curl slightly before breaking.

45. Fusion welding of gray cast iron.—*a.* This metal consists of 90 to 94 percent metallic iron, which is combined with varying proportions of carbon, manganese, phosphorus, sulfur, and silicon. A special, high strength grade of this metal contains, in addition to these elements, 1.5 percent nickel and 0.5 percent chromium. The total carbon in gray cast iron is usually between 3 and 4 percent. Of this amount 0.25 to 0.75 percent is combined with the metal while the remainder is in the form of precipitated graphite. The large proportion of graphitic carbon present gives the metal a gray color approaching a black as the amount increases. This metal is soft, brittle, and easily machined, a quality derived from the nature of the carbon present. The silicon content of cast iron assists in throwing out graphitic carbon as the metal cools from the molten state. In addition to softening the metal by this means, silicon also increases the fluidity of the molten metal and lessens the shrinkage upon cooling. Sudden cooling has the effect of overcoming this characteristic and results in all of the carbon present being dissolved in the iron, forming iron carbides which make the metal extremely hard. When cast iron is melted with the welding flame or other means, all of the carbon is dissolved and combined with the iron and as it cools most of the carbon separates to form graphitic carbon, while the remainder is retained in the iron in the form of iron carbides. Some of the carbon will always remain in the combined state, but the proportion of combined carbon in a casting that has been slowly cooled will be small as compared with that precipitated as graphitic carbon. It will be seen, therefore, that the form of carbon present is largely regulated by the rate of cooling from the molten state.

b. Gray cast iron is used for parts requiring rigidity and resistance to wear. It is also adaptable to parts that are moderately stressed or subjected to passive loading, such as automobile cylinder blocks, pis-

tons, and piston rings, as well as machinery parts, such as gears, flywheels, and pulleys. The tensile strength of ordinary gray cast iron is about 20,000 pounds per square inch for castings of thin cross section and 24,000 pounds per square inch for castings of heavy cross section. The higher grade metal containing nickel and chromium has a minimum tensile strength of 35,000 pounds per square inch. Gray cast iron melts at 2,200° to 2,400° F. The coefficient of linear expansion is 0.006 inch per foot for each 100° F., while the shrinkage of molten cast iron is $\frac{1}{16}$ inch per foot for heavy castings and $\frac{1}{32}$ inch for thin castings.

c. Gray cast iron is considered the easiest of the ferrous castings to weld by the fusion method with the oxyacetylene flame. The weld when properly made has a fine grain structure and is soft and easily machined. The strength of the weld metal is usually greater than that of the base metal. The principal difficulties encountered in welding this metal by the fusion method are the overcoming of hard spots and the control of expansion and contraction forces, which have a tendency to distort the casting or cause additional breaks to appear at different points.

(1) Hard spots in the weld metal may be overcome by using a high grade filler rod, a good grade of welding flux, correct torch and rod manipulation, and slow cooling from the welding temperature. Breakage and distortion may be avoided by preheating and cooling after welding. Any good grade of commercial cast iron welding flux is satisfactory for welding this metal. The flux is used to float the oxides and impurities so that a sound nonporous weld can be produced. Flux should be added by dipping the hot end of the filler rod in the dry powder, as sufficient flux will adhere to the rod for each application. Care should be taken not to add more flux than is needed to keep the impurities floating to the surface and the molten metal clean.

(2) The welding technique, with reference to torch and rod manipulation, is somewhat different from that used in welding steel and other metals. The end of the filler rod should be brought to a red heat before placing it in the melting pool of the base metal to prevent chilling the weld. When metal is being added to the weld, the pool should be stirred continuously with the rod to help float the oxides and impurities. Occasionally some impurities will be trapped in the pool and when this occurs a blowhole will appear as the metal solidifies. These impurities should be removed as the weld progresses by melting beneath them and raking them out with the filler rod. When the rod is removed from the weld, it should be dipped in the flux before being returned to the molten pool. The welding flame must be kept neutral and the tip size must be large enough to keep

the metal melting freely. The backhand method of welding is preferable, as the molten metal and depth of fusion are more easily controlled.

(3) When a gray iron casting is to be welded, the metal surrounding the break should be thoroughly cleaned. All scale, rust, sand pockets, and other impurities must be removed if a clean, sound, machinable weld is to be obtained. Grease or oil may be removed with a rag saturated in gasoline while scale or rust requires sand blasting or grinding.

(4) If the metal is heavier than 1/8 inch in cross section, the edges to be welded should be beveled in the same manner as described for steel plate or bar. Cracks or breaks in castings that cannot be removed for beveling may be chipped out with a round nose or diamond point chisel. They may also be ground out if a flexible shaft or portable grinder is available. When castings are broken in several pieces and have no machined surfaces that can be used to line them up, two or three point. along the break should be left untouched. These points may be used as references to match and line up the pieces. The sections that are not beveled must be melted and raked out with the filler rod, then filled in with new metal after the beveled portions have been welded.

(5) Gray iron castings should always be preheated in order to prevent expansion and contraction strains and hard spots in the weld metal. In the case of a cast iron bracket or bar having but one section to be welded, only the ends at the break will need to be heated before starting the weld. This can usually be done with the welding flame, and the parts should be brought to a full red heat for 1 or 2 inches on either side of the joint. In some cases, castings which have two or more sections can be welded by local preheating, using the method illustrated in figure 35. The object of heating at the points indicated is to keep the expansion of these sections equal to the area being welded, thus reducing severe strains. The points indicated in the figure should be raised to a full red heat before starting to weld and must be kept hot until the weld is completed.

(6) Cored gray iron castings, such as cylinder heads, cylinder blocks, gear cases, and similar parts, usually require preheating of the entire unit before making a fusion weld, although in some few cases where only a boss or lug is broken off, local preheating with the welding flame is sufficient. When the entire casting requires preheating, a furnace can be built around the part with fire brick and the casting heated with charcoal or a preheating torch.

(*a*) When charcoal is used, the furnace should have six or eight draft holes located around the bottom and made about the size of a

half brick. In order to control the temperature of the preheating fire a brick should be placed at each of the openings to regulate the draft by opening or closing the hole. The casting should be covered with charcoal then ignited at each of the draft openings. Care must be taken to prevent the fire from burning too rapidly as slow heat is essential in order to maintain even expansion. The preheating temperature for castings of this type is about 1,200° F. (a medium cherry red). When this temperature is reached, the draft holes should be closed and the charcoal removed from the break. The weld may then be made without exposing the casting to the air more than is absolutely necessary by covering all points with asbestos paper except where the welding is to be done. After the weld is completed, the castings should again be covered with charcoal and the fire permitted to burn until the original preheating temperature is reached. The draft holes must then be closed and the furnace covered and left to cool down.

(*b*) When preheating castings with a flame of any kind, care must be taken to prevent local overheating at any one point. This may be done by placing a baffle of fire brick in front of the casting and directing the flame against it. This will cause the flame to spread and envelop the furnace to give an even temperature around the casting. When preheating with a flame it is necessary to shut off the preheating torch during the welding operation, and because of this the casting must be well protected from drafts to prevent rapid cooling. It is sometimes necessary to stop welding and reheat in order to keep the casting hot enough to prevent strains. Figure 56 shows the construction of a temporary furnace for preheating with a flame. The same type of furnace can be used for preheating with charcoal, although the double wall is not necessary and more openings at the bottom are required to admit air for the fuel.

46. Bronze welding of gray cast iron.—*a*. Bronze welding of gray cast iron is employed in many cases in preference to welding by the fusion method. This process may be used in the repair of broken or cracked cylinder blocks, cylinder heads, and machine castings. The replacement of worn surfaces, the building of new teeth in gears, and the fabrication of cast iron pipe lines are also examples of its application. The advantage in using bronze in welding gray iron castings is the mild heat needed to apply it properly. The bronze does not require extensive preheating and in some cases the parts may be welded without dismantling. The weld and adjacent metal are always soft and expansion and contraction strains are reduced to a minimum. Castings which are used for parts subjected

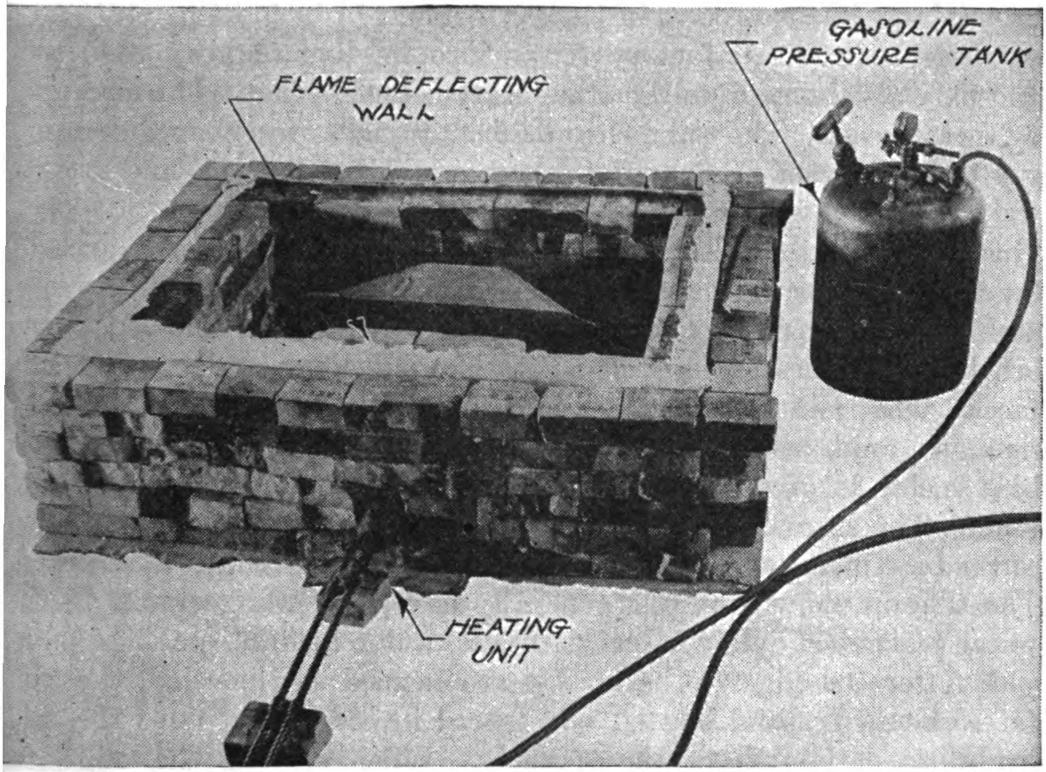


FIGURE 56.—Temporary preheating furnace.

to high temperatures must not be bronze welded, as the strength of this metal is not reliable at temperatures of 1,000° F. and above.

b. Bronze welding rods are manufactured by several concerns under such trade names as Tobin bronze, Roman bronze, Manganese

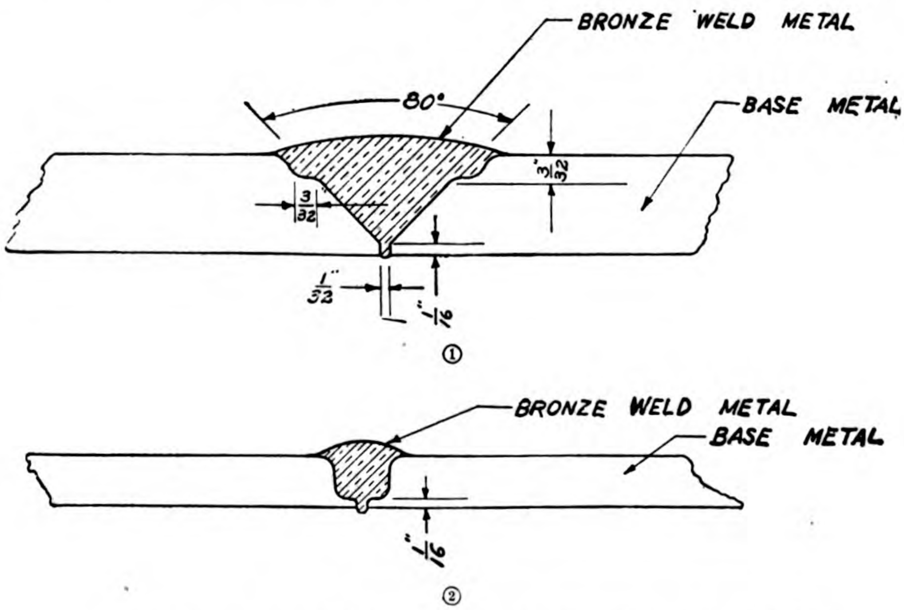


FIGURE 57.—Recommended joints for bronze welding of cast iron.

bronze, and Purox bronze, in $\frac{1}{16}$, $\frac{1}{8}$, $\frac{3}{16}$, and $\frac{1}{4}$ inch diameters. Any of these rods is satisfactory for bronze welding of gray cast iron and may also be used on the other ferrous metals that require joining by this process. The rod melts at 1,625° F., flows freely, and does not gas to any extent at temperatures required for brazing and bronze welding.

c. When welding cast iron with bronze, the metal in the area of the weld must be thoroughly cleaned to remove all scale, rust, grease, and oil. The parts to be welded should be beveled and all sharp breaks or corners ground off to give round edges and smooth surfaces. The joints (fig. 57① and ②) will develop the highest strength weld, as the area of the bond between the bronze and the base metal is greater than is obtainable with the ordinary 90° V joint. The shear V joint shown in ① will develop the full strength of the base metal and should be used where high strength is required. The U joint shown in ② is generally used in welding cracks in the water jackets of cylinder blocks, heads, water heaters, etc.

d. After the edges to be welded are cleaned and beveled, the surfaces should be sand blasted and seared in order to remove the free graphitic carbon from the surfaces. When searing the edges, a slightly oxidizing flame should be moved along the seam with the central cone touching the metal. The free carbon will combine with the excess oxygen in the flame and leave the iron exposed so that a better bond may be obtained. Care must be used during this process to prevent raising the temperature of the metal above a blue heat.

e. After sand blasting and searing, the edges should be coated with a thin film of flux dissolved in hot water. A mixture of 3 parts of boric acid to 1 part of borax is a suitable flux for bronze welding of the average gray iron casting, although there are some special fluxes on the market which are highly recommended. One of the best of these prepared fluxes is known by the trade name of "A-malgam cast iron bronze welding flux" and may be obtained from retailers of welding supplies. The flux should be applied during the welding operation, either by dipping the hot end of the rod in dry flux or by painting the dissolved flux on the rod before starting to weld. When the boric acid and borax mixture are used, it is preferable to apply the dissolved flux to the rod. This insures a more even distribution and keeps the metal well protected at all times.

f. There are occasions when it is necessary to preheat castings for bronze welding to prevent the expansion and contraction strains

from developing additional cracks. Cored castings which are cracked or broken on their flat surfaces, or flat, thin castings that require welding, should be preheated in a furnace to about 800° F. This temperature can be determined by touching the hot casting with a pine stick, which will char immediately when this temperature is reached.

g. The application of bronze to cast iron requires careful attention if a good bond between the two metals is to be obtained. If the metal becomes too hot, the bronze will ball up and fail to adhere to the cast iron, whereas if it is too cold when the bronze is applied, it will not spread out and adhere to the casting. The flame should be slightly oxidizing for the bronze welding of cast iron and must be large enough to raise the metal quickly to a full red heat at the point where the weld is to be started. The object of using an oxidizing flame is to free the graphitic carbon that comes to the surface as the metal is being heated to the welding temperature, as this has a tendency to prevent the bronze from adhering. The free carbon combines with the excess oxygen in the flame and burns away, leaving the surface clean. After the tinning coat is applied, the flame may be changed to neutral to prevent oxidation of the bronze welding material, but in case the weld requires only one layer of bronze, the flame should carry an excess of oxygen for the entire weld.

h. When starting the weld, the flame should be applied a little back from the seam until the weld area becomes a full red. Upon application, the bronze should spread quickly and tin the heated area if the proper flux is used. After the first tinning application, the seam may be built up to the required thickness, then continued by tinning the edges for a short space and building up the bead as required to provide ample reinforcement for the type of joint being made. If the metal becomes too hot and the bronze refuses to adhere, the weld should be transferred to another point and the metal allowed to cool.

i. When welding a crack or break that terminates in a hole or opening in the casting, the weld should progress toward this point. In long seams on flat surfaces, the weld should progress from the ends of the brake toward the middle, and in the case of branch cracks, the weld should start at the end and progress toward the main crack or seam. It is considered good practice to drill a small hole ¼ to 3/16 of an inch in diameter at the end of a crack or break to permit the force of expansion to be distributed around the circumference of the hole, thus preventing the fracture from spreading. Bronze welds in gray cast iron should be cooled slowly to prevent contraction strains which may cause distortion or breakage.

47. Welding malleable iron castings.—*a.* Malleable iron is cast from the molten state as hard, white iron and is made malleable by a special heat treatment. Pig iron, together with cast iron scrap and a little scrap steel, is melted in an air furnace or cupola. The melting and pouring are so regulated that practically all of the carbon in the castings will be combined as iron carbide. This constituent makes the material hard and very brittle and gives it a white crystalline structure. The castings are then annealed for a sufficient time to break down the iron carbide into iron and carbon. The process of annealing is accomplished by packing the castings in cast iron or steel annealing boxes where they are completely surrounded with iron oxide. The boxes are then placed in an annealing furnace and heated slowly to the required annealing temperature, which is from 1,300° to 1,450° F. for air furnace castings and 1,500° to 1,600° F. for cupola castings. The annealing operation requires about 6 days, of which from 48 to 60 hours are at the annealing temperature, the rest of the time being consumed in heating and cooling. During this process the iron carbides dissociate into iron and carbon in the interior of the metal while the outer surface becomes decarbonized, leaving a tough, malleable skin or veneer of iron surrounding a soft, brittle interior. In mechanical properties, malleable cast iron is stronger than gray cast iron and weaker than steel. The maximum tensile strength obtainable is about 52,000 pounds per square inch. It is capable of being bent and hammered flat without cracking. Malleable iron is used extensively for machine parts where high strength castings are essential. Pipe fittings and numerous other small articles subjected to hard wear are also made of malleable iron.

b. This metal cannot be welded satisfactorily by the fusion method unless it can be heat-treated. This is due to the fact that if the metal is melted the malleable property that was obtained by heat treatment will be destroyed in the weld area and the metal will become weak and brittle. Welding with bronze is the only practical method of joining broken parts of malleable iron castings. In this case, the metal is not heated to a temperature that will destroy the effect of heat treatment, and the joint will be equally as strong as the casting when the weld is properly made.

(1) To weld malleable iron castings effectively with bronze, the metal at the break should be cleaned until bright and the edge of each piece beveled to 45° from one or both sides, leaving a square shoulder of $\frac{1}{16}$ inch or less at the bottom of the V. Castings with heavy cross sections should always be beveled from both sides when possible.

(2) The filler can be any good grade of bronze welding rod, and its size will depend upon the cross section of the casting. A 3/16 inch diameter rod is satisfactory for the average work.

(3) A flux is used to cleanse the metal and protect the bronze welding material. Any good prepared brazing flux is satisfactory, and if not available a mixture of 75 percent boric acid and 25 percent borax will give the desired results. The flux is added to the weld by dipping the hot end of the welding rod in the dry powder.

(4) In making the weld, the surfaces in the V should first be tinned with the welding rod and the joint then completed by building it up with successive layers of welding material. A bead height of 1/8 inch above the surface of the base metal should generally be used for reinforcement, and the bronze laid on so it will taper gradually to the base metal at each side of the joint. After the weld is completed, the work should be cooled slowly as rapid cooling is apt to make the base metal brittle in the area around the weld.

48. Welding semisteel castings.—*a.* Semisteel is a product of pig iron, scrap cast iron, and mild steel melted in a cupola and cast in the same manner as gray cast iron. It is stronger than gray cast iron but has similar characteristics. Semisteel contains 2.40 to 2.75 percent graphitic carbon and 0.3 to 0.5 percent combined carbon. The silicon content ranges from 1 to 2 percent and the manganese about 0.50 percent. Semisteel has a maximum tensile strength of 35,000 pounds per square inch and has a high resistance to shock. The metal is nonductile and the elongation has a very low unit value. It is close grained and free from hard spots. In structure it is more closely allied to malleable cast iron than gray cast iron. Semisteel machines more readily than gray cast iron and this, in addition to its high resistance to shock, makes the metal especially suitable for cylinder blocks, pistons, and machine parts.

b. This metal can be joined either by fusion or bronze welding. Bronze welding is preferable as the structure of the metal will not be disturbed at the low temperature required, and a strength equal to the base metal may be obtained. Ordinary rod and flux may be used and any of the joints previously described is satisfactory. Some preheating is necessary if the casting is of the cored type having two or more sections. The heating should be done in a furnace and the welding operation performed in the same manner as described for preheating and bronze welding of gray iron castings. In case it is desired to weld this metal by the fusion method, a cast iron welding rod should be used and the welding operation performed as in making a weld in gray cast iron. Preheating is necessary and the metal must

be allowed to cool slowly after the weld is completed. A fusion weld should not be used where the full strength of the metal is required.

49. Welding steel castings.—*a.* (1) Most steel castings are similar in composition to steels obtainable in the bar, sheet, and tubular forms. The grade of steel casting used in aircraft construction is generally plain carbon steel, containing a maximum of 0.45 percent carbon. This grade of steel casting is used for tail skid fittings, landing gear fittings, and miscellaneous parts where the design would be difficult to fabricate by welding.

(2) Manganese steel castings are used for some aircraft parts where hardness and high resistance to wear and abrasion are essential, such as tail skid shoes. Commercially it is extensively used for digging machinery, plows, etc. This metal contains 1.0 to 1.40 percent carbon and 10.0 to 14.0 percent manganese. After casting, it is hard and brittle and is practically unmachinable. Castings of this metal, quenched in water from a red heat, become very tough and ductile, although they cannot be annealed to machine readily.

b. The welding procedure for cast steel will depend on the composition of the metal and the nature of the casting.

(1) The plain carbon steel castings are welded with the same kind of rod recommended for welding similar steel in the form of sheet, tubing, plate, and bar. If the cross section of the casting exceeds 1/8 inch where the weld is to be made, the edges should be beveled in the same manner as described for sheet or plate 1/8 inch or more in thickness. Steel castings, except those used for aircraft parts, may be bronze welded with a resulting high strength joint. Steel is more easily bronze welded than gray cast iron because there is no graphitic carbon to prevent penetration into the pores of the metal.

(2) (*a*) Manganese steel castings present a different problem from a welding standpoint. The metal is very weak at high temperatures and should be supported during welding. Preheating of castings and forging must be avoided when possible. The welding rod should be about the same composition as the base metal and the American Welding Society specifications for manganese steel welding rods recommended 1.10 to 1.35 percent carbon, 11 to 14 percent manganese, 0.017 to 0.04 percent phosphorus, 0.007 to 0.04 percent sulfur, and 0.10 to 0.20 percent silicon.

(*b*) The majority of welding required for manganese steel parts is the building up of worn surfaces. Where this operation is to be performed, the metal should be thoroughly cleaned and the casting submerged partly in cold water in order to keep it cool at points

other than the portion to be welded. A slight excess of acetylene should be used in the flame and. after fusion is established, the end of the filler rod must be kept in the pool of molten metal. Only a small quantity of metal should be placed at a time, and the weld should be quenched frequently by throwing cold water on the deposit. Air bubbles that form during the process may be peened out with a hammer. Quenching and hammering improve the quality of the deposits, as quenching makes the metal tougher and hammering relieves contraction strains and improves the grain structure. After the weld is completed, it is recommended that the entire casting be heated to a temperature of approximately 1,250° F. for ½ hour and then quenched in warm water. When welding manganese steel with the oxyacetylene flame, the metal sometimes tends to foam. If this occurs, a very fine aluminum wire should be wound around the filler rod in long spirals. The introduction of this small quantity of aluminum in the melting pool will considerably reduce the bubbling of the metal.

Section VII

CUTTING METAL BY THE OXYACETYLENE PROCESS

50. Principles of cutting.—*a.* Cutting metals by the oxyacetylene process is fundamentally the rapid burning or oxidizing of the metal in a localized area. The metal is heated to a bright red or "kindling" temperature and a free jet of high pressure oxygen is forced against it. This oxygen blast combines with the hot metal to burn it to an oxide, and the resultant reaction generates an intense heat which is taken advantage of in cutting. The high temperature oxide heats the metal in its path to the ignition temperature as it rolls down the side of the cut. The area thus affected combines with the cutting oxygen and also burns to an oxide which is blown away on the opposite side of the piece, leaving a narrow slot or "kerf" separating the metal.

b. Although practically all metals will combine readily with oxygen when brought to a high temperature, some of them cannot be successfully cut by this method as their oxides have a higher melting point than the parent metal and mix with it when melting instead of separating. The nonferrous metals and the high chromium stainless steels are those which come in this class. Cast iron does not cut easily but may be melted and the molten metal blown away by the high pressure oxygen.

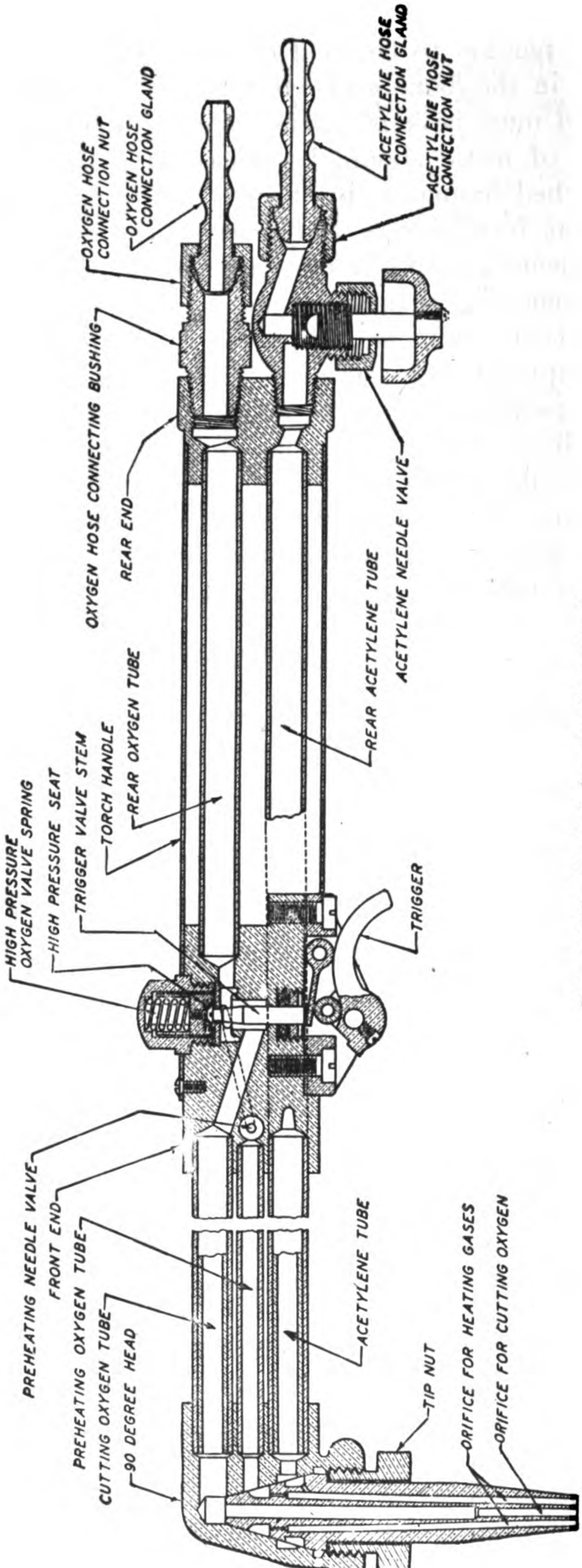


FIGURE 58.—Typical hand cutting torch.

In cutting cast iron there is a rather wide kerf which is very uneven in the poorer grades of metal. In summary, the only metals that may be cut readily without some special preparation are the wrought irons and carbon steels that have a carbon content low enough to prevent the metal from becoming hard and brittle upon sudden cooling.

51. Cutting equipment.—*a.* The oxyacetylene cutting equipment is the same, in general, as the welding equipment, with the exception of the torch, although the oxygen regulators used for heavy cutting operations are designed to furnish a larger volume and higher pressure than are required for welding. In this case, the oxygen outlet is fitted with a working pressure gage which is graduated to 400 pounds per square inch, and the oxygen hose is designed to withstand these higher pressures.

b. Cutting torches may be either hand or machine operated and figure 58 shows the construction and operating principles of a hand cutting torch. Machine cutting torches are similar in design to the hand torch with the exception that they have attachments for connection to the machine for which they are designed. All cutting torches have an extra tube and valve for the passage and control of the cutting oxygen and are provided with separable tips of different sizes for cutting various thicknesses of metal. These tips have two or more holes for the passage of acetylene and oxygen used to produce the heating flames. These holes are equally spaced around a central hole through which the high pressure oxygen is fed.

c. Cutting machines are available for cutting metal in practically any shape or pattern desired. Some of these machines are guided by means of a template while others are fitted with a tracing wheel which is guided by the operator over the outline or drawing of the shape being cut. These machines are available with either manual or motor driven torches and may be portable or stationary. For production work cutting machines are often made partly or almost fully automatic. Figure 59 shows a straight line portable motor-driven cutting machine of a popular type. This machine and the torch which is mounted on it are guided along the line of cut by means of a track. The machine is adjustable to accommodate the speeds required for the various cutting conditions, and a radius rod with center head is provided to guide the machine for circular cutting.

52. Procedure for cutting low carbon steel.—*a.* As previously stated, low carbon steels may be cut without any special preparation although they must be clean on both sides along the line of cut. Any scale or other substance that will not readily oxidize will cause the cutting oxygen stream to spread and result in a wide, uneven kerf as well as the forming of pockets. When applying the torch, the

heating flame should be adjusted to neutral. The pressure of oxygen, size of cutting nozzle, and speed of cut depend entirely upon the thickness of metal. Manufacturers of cutting torches and machines furnish charts with their equipment giving such information. These charts should be used as a guide for best results. In the absence of such a chart both the following table and figure 60 may be referred to for an approximate calculation of these variables.

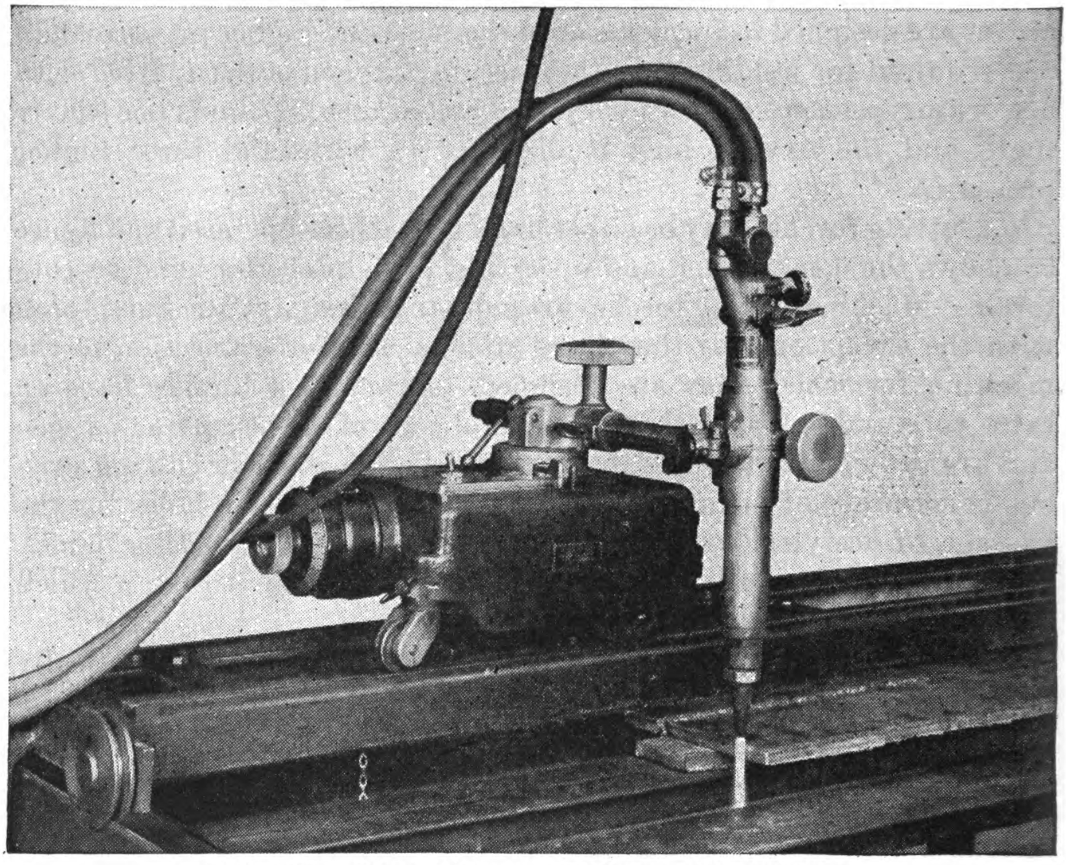


FIGURE 59.—Motor-driven oxyacetylene cutting machine.

TABLE X.—*Recommendations for cutting low carbon steel*

Metal thickness (inches)	Diameter of cutting orifice (inch)	Oxygen pressure pounds per square inch	Acetylene pressure pounds per square inch	Cutting speed (inches per minute)
¼	0. 0380–0. 0595	11–20	3	16–26
½	. 0465– . 0595	20–30	3	12–22
¾	. 0465– . 0595	24–35	3	12–20
1	. 0465– . 0595	28–40	3	18–19
1½	. 0595– . 0810	30–40	4	6–15
2	. 0670– . 0810	32–50	4	6–13
3	. 0670– . 0810	33–55	4	4–10
4	. 0810– . 0860	42–60	5	4–8

b. When hand cutting straight lines the torch should be guided by means of a bar clamped on the work parallel to the line of cut. The torch may then be held against this bar and advanced steadily to give a uniform cut through the metal. The tip of the heating flame central cone should be held slightly above the surface of the metal with the cutting nozzle at right angles to the surface of the

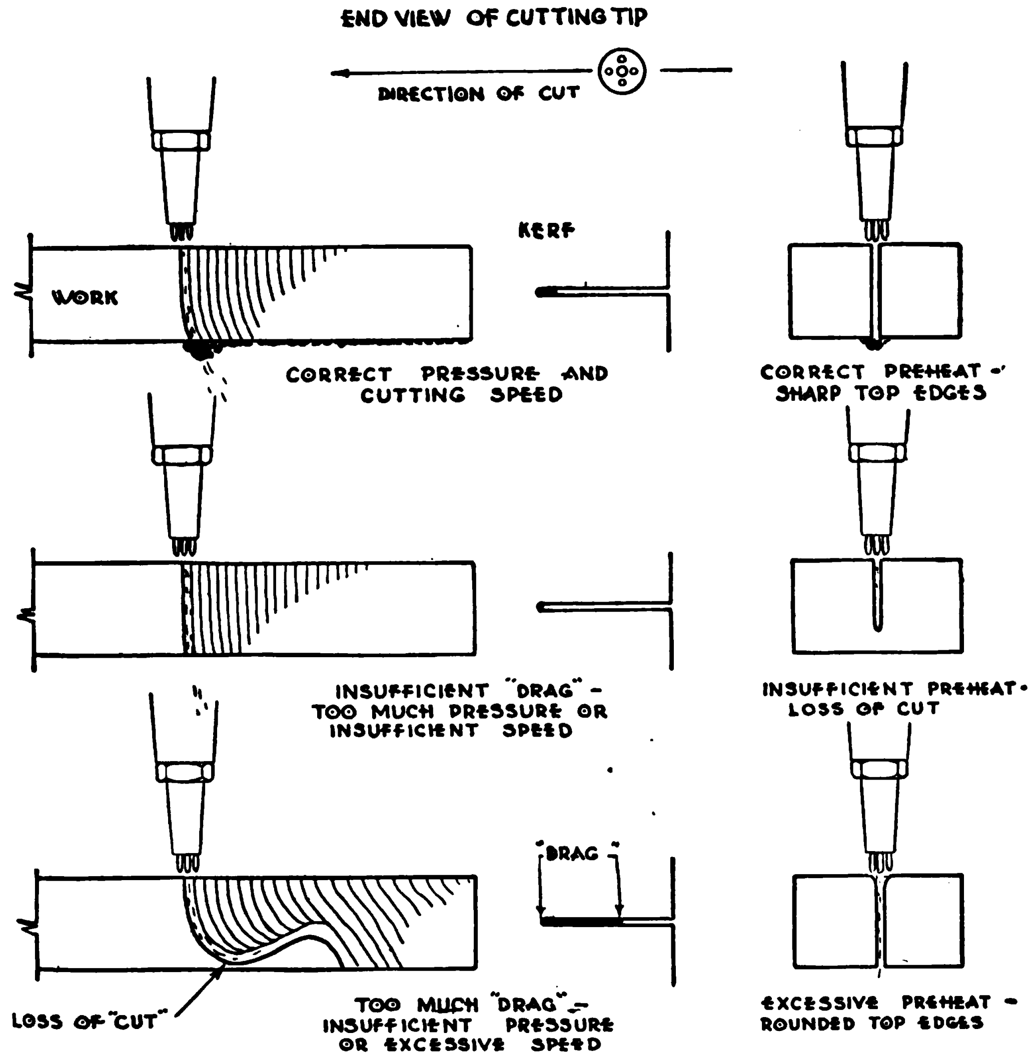


FIGURE 60.—Sight method for determining correct cutting procedure.

metal for square edge cuts. For sheet, plate, and flat bar stock the cut should always be started at the edge. In cutting heavy plate or bar stock it is good practice to undercut the lower edges (fig. 61) in order to facilitate starting and finishing the cut.

c. Circular cutting with a hand cutting torch is accomplished by means of a radius bar with center point which attaches to the torch head. Where the cut must be started away from the edge of the

metal, a ¼ to ⅜ inch hole should be bored at the line of the cut or a hole burned through the metal a short distance from this line and the cut started from the edge of the hole.

d. In the cutting of round bar stock, a bur should be raised on the surface of the metal with a round nose chisel at the point where the cut is to begin. This preparation makes it possible to start the cut without prolonged heating. The cut should be started at the side about 90° from the vertical diameter with the cutting nozzle inclined slightly (fig. 62). After the cut has been started, the torch head should be raised to a vertical position and held in this way for the remainder of the cut. The heating flame cones should be held about the same distance from the surface of the metal as in cutting plate or flat bar stock.

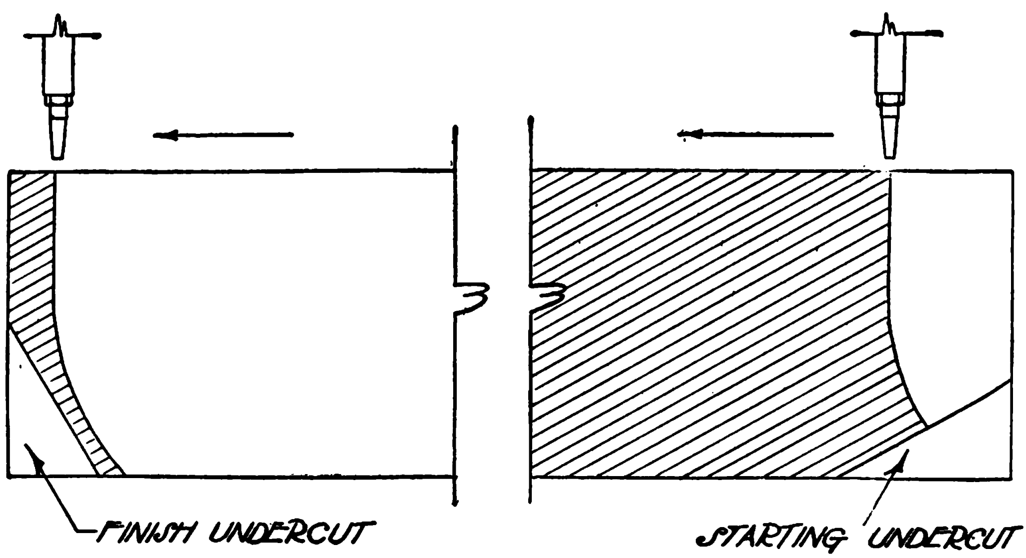


FIGURE 61.—Preparation for heavy cutting.

53. Procedure for cutting high carbon and alloy steels.—*a.* High carbon and alloy steels used for parts that require heat treatment or steels that will harden on sudden cooling from a high temperature must be preheated to between 500° and 600° F. before being cut. This precaution is necessary to prevent checking or cracking along the edge or face of the kerf, as the metal becomes very hard and brittle when cooled quickly from a high temperature. When cut without being preheated, the metal next to the kerf will absorb the heat rapidly enough to cause about the same effect as quenching in water. Since the ductility of these metals in a hardened condition is very low, they will not yield enough to contraction strains to prevent cracking.

b. Some special provision must be made when cutting the high chromium "stainless steel" sheet and plate. Several methods may be used and are described as follows:

(1) By the use of two iron or low carbon steel bars clamped on opposite sides of the metal directly over the line of cut. In this manner, the oxides of the carbon steel or iron combine with the oxides of the alloy steel causing it to be carried away to effect the cut.

(2) By the laying of a bead of low carbon steel along the line of cut with the electric arc. This procedure serves the same purpose as the use of steel plates and is particularly adaptable to certain types of jobs.

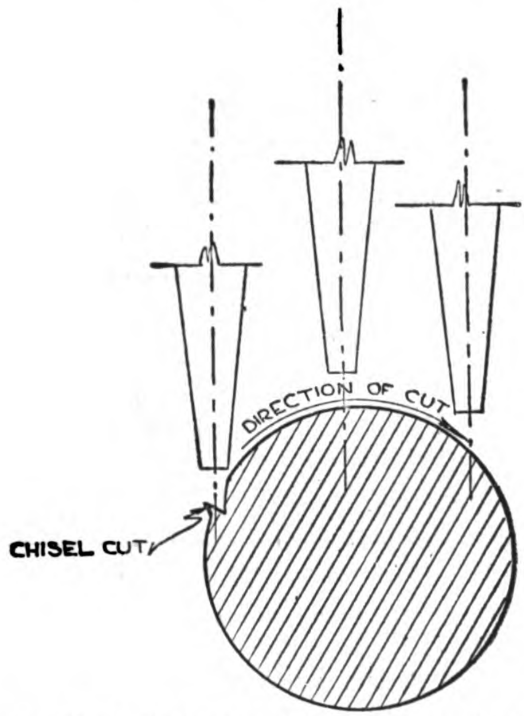


FIGURE 62.—Technique used in cutting round stock.

(3) By the use of a low carbon steel bar or rod applied during the cutting process. When this method is used, the bar or rod is manipulated along the line of cut and the jet of oxygen directed upon it. The results are similar to those obtained by the use of the methods mentioned above.

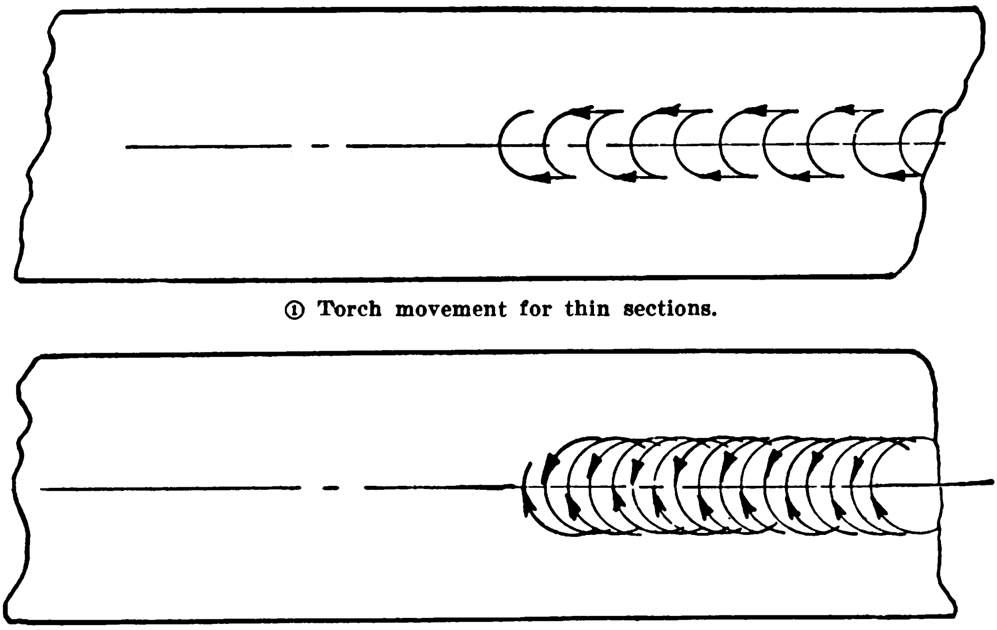
54. Procedure for cutting cast iron.—*a.* In cutting cast iron the preheating flame is adjusted to a highly carbonizing setting. The length of the brushlike second cone produced by the excess of acetylene should be equal to the metal thickness. This flame adjustment

aids in maintaining the preheat along the line of cut as the excess acetylene combines with oxygen from the cutting stream.

b. The technique of starting and maintaining a cut in cast iron is as follows:

(1) Preheat along the proposed line of cut for 2 to 3 inches.

(2) Move the torch back to where the cut is to start and heat a ½ to ¾ inch area to a bright red by giving the torch nozzle a swinging motion.



① Torch movement for thin sections.

② Torch movement for thick sections.

FIGURE 63.—Torch manipulation for cutting cast iron.

(3) Move the nozzle to the edge of the heated area and open the cutting oxygen valve quickly with the torch nozzle held 30° to 45° to the work, pointing toward the line of cut.

(4) After the cut is established, keep the torch in motion and change the angle so that the tip points at approximately 75° toward the finished cut (fig. 63). The movement shown in figure 63① should be followed for thin castings while the one shown in ② is recommended for heavy sections.

Section VIII

WELDING ALUMINUM AND ALLOYS OF ALUMINUM AND MAGNESIUM

55. Aluminum and its alloys.—*a.* Aluminum in its pure state is a white, lustrous metal that is noted for its lightness, corrosion resistance, malleability, and ductility. Commercially pure aluminum in the wrought condition is designated as 2S in the series of numbers used to classify these metals. The suffix "S" indicates that the material is wrought. This metal is obtainable in the bar, sheet, tube, and wire forms, in the annealed ¼ hard, ½ hard, or ¾ hard condition of temper. The half hard temper is most often used for aircraft parts fabricated of sheet. All forms and tempers of this metal can be welded readily with either the oxyhydrogen or oxyacetylene flame, and sheet, plate, or bar stock ⅛ inch thick or heavier, can be welded with the arc. The oxyhydrogen flame is preferable for all light gages.

b. The weldable aluminum alloys used in aircraft construction are designated as 3S, 43S, and 52S. Alloy Nos. 51S and 53S may also be welded, but as they are in the heat-treated condition, welding should not be done unless the parts can be reheat-treated.

(1) The 3S alloy is used in many cases for the same purpose as 2S or pure aluminum and is obtainable in the same forms and tempers. The metal is an aluminum-manganese alloy and its weldability is about the same as that of pure aluminum.

(2) No. 43S is an aluminum-silicon alloy. This metal is manufactured in the wire form and is also used for some castings. Gas welding rods for all weldable aluminum alloys except 3S are made of this material as it fuses readily in either the wrought or cast forms.

(3) No. 52S is an aluminum-magnesium-chromium alloy and is used in the sheet and tube forms for some aircraft parts.

56. Welding No. 2S aluminum and No. 3S alloy.—*a.* (1) The welding temperature for these two metals is very much the same as their melting point and both require the use of an energetic flux as

they are coated with a film of oxide which tends to prevent fusion of the melting metal. Flux used for welding aluminum and its alloys must be capable of dissolving the oxides quickly, and the dissolving capacity must be sufficient to take care of all oxides that form during welding. It must melt at a temperature below the metal, and the molten flux with the oxide dissolved in it must have a specific gravity sufficiently below that of the molten metal to cause it to come readily to the surface. Flux filling the above requirements may be obtained from any reputable manufacturer or distributor of welding supplies.

(2) Flux should be used sparingly but in sufficient quantities to dissolve all oxides encountered. The flux is supplied in a powder form and must be mixed with clean water to form a paste about the consistency of cream. When a filler rod is used in making the weld, application of the flux to the rod is usually sufficient. If a joint is made without the use of a filler rod, a thin film should be brushed on the edges of the metal before starting the weld. Only enough flux should be prepared at one time to last for the day's work as it has a tendency to crystallize and lump upon standing. The container for the mixed flux should be aluminum, brass, glass, or earthenware, as steel or iron will contaminate it with impurities that will destroy its purpose. Containers for the unmixed flux must be kept tightly closed to prevent absorption of moisture from the atmosphere.

b. (1) The weldable aluminum alloys lose their ductility when heated near their melting point, and if strained at this temperature will often crack in the heated area. For this reason, some provision must be made to relieve shrinkage strains which are set up due to contraction on cooling from the welding temperature.

(2) When welding aluminum sheet, contraction strains can be reduced to a great extent by forming corrugated beads parallel to the seam ½ to ⅝ inch from the edges. This same effect may also be obtained by making a slight depression in the sheet near the seam. Buckling caused by expansion can be reduced by the use of cold packs or a batten composed of wet asbestos fiber laid along the sheet 1 or 2 inches from the seam. Slight distortions or buckled areas are not serious in these metals as they are soft after welding and may be hammered or rolled out.

c. Drawn 2S wire is generally used as a filler rod for welding 2S aluminum and 3S alloy, although thin strips cut from 2S sheet may also be used for this same purpose. In welding with a rod, care should be taken in selecting the proper size for the thickness of metal being joined, as the rod absorbs heat from the welding flame in proportion to its size. The rod used must melt at the proper time when added to

the weld in order to prevent chilling the molten pool. On the other hand, if the rod is too small it will not chill the pool quickly enough to keep it from sagging. The rod sizes recommended for welding various thicknesses with the oxyhydrogen or oxyacetylene flame are given in table XI.

TABLE XI.—*Welding rod sizes for 2S and 3S aluminum alloys*

Thickness of metal (inch)	Diameter of welding rod (inch)
Up to 0.028	1/16
0.028 to 0.0625	3/32
0.0625 to 0.125	1/8
0.125 to 0.250	3/16

d. (1) Only a neutral flame should be used in welding the 2S and 3S alloys. The torch must be adjusted to give the mildest flame that can be obtained without popping, as the use of a strong, harsh flame makes it difficult to control the melting metal, and holes are often burned through.

(2) Table XII may be referred to for selecting the size of tip and pressure of gases for welding the various metal thicknesses with an equal pressure type oxyacetylene torch.

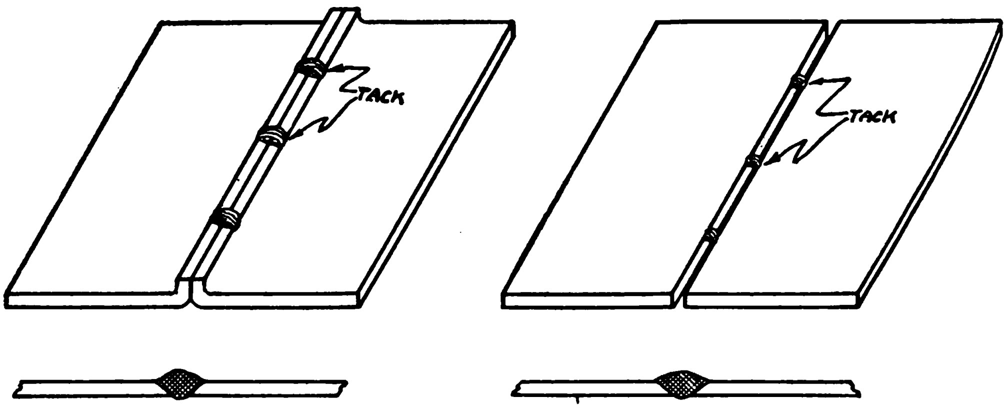
TABLE XII.—*Recommendations for oxyacetylene welding of 2S and 3S aluminum alloys*

Metal thickness (inch)	Size tip (number)	Acetylene pressure (pounds per square inch)	Oxygen pressure (pounds per square inch)
Up to 0.025	0	1	1
0.025 to 0.050	1	1	1
0.050 to 0.0625	2	2	2
0.0625 to 0.093	3	3	3
0.093 to 0.125	4	4	4
0.125 to 0.1562	5	5	5

e. Joints for welding aluminum sheet and plate are the same, in general, as those used in welding steel of a similar thickness. The flanged joint in figure 64①, should be used for butt welds in sheet stock 0.050 inch or under when it is possible to bend the edges. Butt welds in sheet from 0.050 to 0.093 inch are usually made with the joint shown in figure 64②. Figure 65① and ② shows the preparation of

the thicker sheets and plates for butt welding. A description of the procedure used in welding these various joints may be outlined as follows:

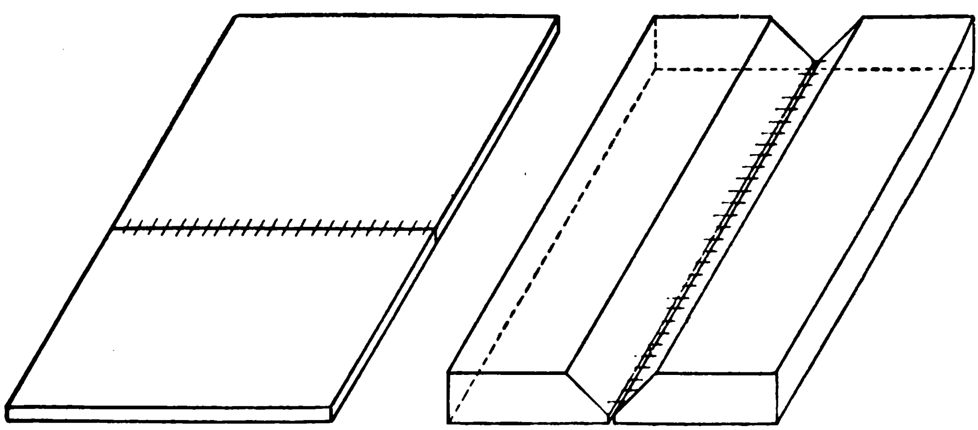
(1) In the flange joint (fig. 64①) the edges are turned up 90° to the face of the sheet, from 1 to 2 times the metal thickness. Lighter gage



① Flange butt joint. ② Square edge butt joint.

FIGURE 64.—Preparation for welding butt joints in aluminum sheet.

metal should have more flange than the heavier stock. In welding this joint, the edges are coated with a thin film of flux, then clamped together and tack welded at equal intervals of 1 to 2 inches. The clamps may then be removed and the weld made by melting down the flanged



① Joint for plate from 0.093 inch to 0.125 inch. ② Joint for plate from 0.125 inch up.

FIGURE 65.—Preparation for welding heavy aluminum sheet and plate.

edges. A constant and uniform movement of the torch is required with the flame directed toward the flanged edges at an angle of 35° to 45° and in line with the seam. The tip of the central cone should be held from 1/16 to 1/8 of an inch from the metal as the weld progresses.

(2) The square edge butt joint (fig. 64②) requires the use of a filler rod. The edges are set up parallel and spaced enough so that when tack welded the shrinkage will draw them almost together. They are tack welded at equal intervals of 1 or 2 inches by melting the edges and applying a small quantity of filler from the welding rod. The rod should be coated with sufficient flux for making the weld, and after tacking if there is excess of metal at any of these points, it should be removed before the joint is welded. The metal should be heated to its melting point where the weld is to be started, and as soon as this temperature is reached the flame should be raised slightly and the rod applied to the melting pool. The torch and rod movement should alternate with the rod being raised as the flame is lowered and vice versa.

(3) The preparation of heavy sheet and plate for butt joints requires notching of the edges as shown in figure 65. These notches are cut with a chisel and should be about 1/16 inch deep and 3/16 inch apart. The notches permit the flux to work down through the full thickness of the metal to insure complete fusion. These notches also act as small expansion joints and help to minimize heat strains. The joint shown in ① is set up with the edges parallel and spaced 1/16 inch apart. A backing plate of copper, made with a groove under the joint to allow for a slight bead on the under side of the weld, is very desirable. A filler rod is used and the weld is made with the same movement as described for welding the plain square edge butt joint.

(4) When welding sheet and plate 1/8 inch and heavier, the edges should be beveled about 45°, as shown in figure 65②. The bevel should be made in such a way as to allow a square edge of 1/16 inch for the lighter gages and 1/16 to 1/8 inch for the heavier gages. This square edge should be notched in the same manner as described above. Plates 3/8 inch and heavier should be preheated to between 700° and 800° F. to minimize heat strains and reduce the amount of heat required actually to weld the joint. It is only necessary to heat a narrow area on each side of the joint, but the preheating temperature should be maintained during the entire welding operation.

57. Welding aluminum alloy No. 52S.—This alloy is very sensitive to strains at temperatures near its melting point. Due to this fact, the work must be supported when hot and the heat strains minimized to prevent cracking and weld failure. Any of the joints previously described are satisfactory, and the weld may be made with the same flame and flux as are used for the 2S aluminum and 3S alloy. An aluminum-silicon alloy welding rod should be used whenever a filler is necessary. When welding sheet stock, a bead should be formed

in the sheet on each side of the joint parallel to and 5/8 to 3/4 inch from the seam as shown in figure 32.

58. Welding the heat-treated wrought aluminum alloys.—*a.* Alloy Nos. 17S, 24S, 51S, and 53S are heat-treated and, although any of them may be made to weld, only the 51S and 53S alloys can be heat-treated after welding to develop their full strength. For this reason, the 17S and 24S alloys are considered nonweldable.

b. The 51S and 53S alloys have characteristics similar to the 52S alloy in respect to ductility and strength at temperatures near their melting point and due to this fact must not be strained while hot. If jigs are used to assemble and hold the parts during welding, they must be designed so that normal expansion and contraction will not be restrained.

c. The welding technique, type of flame, flux, and welding rod used for these metals are the same as recommended for the 52S alloy.

59. Welding aluminum alloy castings.—*a.* Aluminum alloy castings used for aircraft parts and other articles of equipment vary considerably in structure, depending upon their use. The parts may be produced as sand, permanent mold, or die castings in practically any desired shape.

b. All of the cast aluminum alloys can be welded with the oxy-acetylene flame and some may be welded with the arc. Welding of the highly stressed aircraft parts is, however, prohibited as these castings are generally heat-treated. The aluminum-copper alloy, designated as No. 12 or 112, used for ground equipment, may be welded without any hesitancy as this alloy cannot be heat-treated.

c. In welding any grade of aluminum alloy casting, a flux should be used for best results. Castings may be welded without a flux by the so-called "puddling" method which is performed by melting the metal and stirring or puddling it with the filler rod. While it is in a plastic state, the metal may be readily formed with a steel or iron rod flattened on one end. After the joint has been built up to the required thickness, the flat end of the rod may be used to smooth off the weld. The puddling method is not considered as satisfactory as the flux method, as it only breaks up the oxides and leaves them disturbed in the weld metal, thus reducing the strength of the joint.

d. The welding rod used for castings may be either cast or drawn. The cast rod usually used is an aluminum-copper alloy, and the drawn rod is the aluminum-silicon alloy previously described for welding the heat-treatable wrought alloys.

e. When a broken aluminum casting is to be welded, it should first be cleaned thoroughly to remove all traces of oil, grease, or dirt from the area surrounding the break. This can be accomplished by means

of a wire brush and a clean rag or waste saturated with gasoline. If the casting has a heavy cross section at the break, it should be cut out along the fracture to form a 90° V extending to within 3/32 inch of the bottom. In case there are broken pieces to be welded in, they should be held in place with light iron bars and appropriate clamps. The clamps must be attached so that the casting will not be strained from the effects of expansion and contraction. If the casting is large and requires preheating, it should be placed in a heat-treating furnace and brought to a temperature of between 700° and 800° F. prior to starting the weld. The preheating temperature can be determined by rubbing a soft pine stick or tightly rolled piece of paper on the hot casting. When the casting is at the proper temperature, the pine stick or paper will leave a char mark on the metal. The correct temperature can also be determined by sound, as cold aluminum gives a metallic ring when struck, which becomes duller as the temperature is raised, and at the proper temperature for welding, this sound is no longer metallic. If the casting is brought to a temperature above 800° there is danger of distortion and collapse. When a heat-treating furnace is not available, preheating may be done in a temporary furnace (fig. 56). When preheating castings in this manner, it is good practice first to heat the furnace to a temperature of approximately 1,000° F. When this temperature is reached, the flame should be withdrawn and the casting placed in the furnace, covered with asbestos sheeting, and allowed to absorb heat from the furnace for 20 or 30 minutes before returning the preheating flame. This procedure permits the casting to expand evenly and eliminates harmful strains. When using this method of preheating, a baffle built up of brick should always be placed between the casting and the flame.

(1) Castings which have been preheated in a furnace must be brought up to the preheating temperature after welding and then allowed to cool slowly in the furnace.

(2) It is not always necessary to preheat the entire casting, and local heating with the welding flame is sufficient where the repair is such that the metal can expand without setting up excessive strains. Broken lugs, bosses, and cracks or breaks at the edges of castings can often be built up with weld metal or welded back in place in this manner.

60. Cleaning and finishing aluminum after welding.—*a*. In many cases, welds in aluminum and its alloys do not require any finishing except the removal of the welding flux. All aluminum welding fluxes are corrosive to the metal and must be removed im-

mediately after the part has cooled enough to be handled. Removal may be accomplished in the following manner:

(1) Wash the part thoroughly in hot water.

(2) Apply a 5 percent solution of nitric acid or a 10 percent solution of sulfuric acid.

(3) Remove all traces of the acid by again washing in clean hot water.

b. Welds in 2S aluminum and 3S alloy may be finished flush with the surface if required. The weld can be hammered and rolled or the excess weld metal removed by grinding or filing to give a smooth, even finish. Hammering should not be used on the heat-treatable alloys unless they are in the annealed condition. Welds in castings should be finished smooth if there is an excess of weld metal at any point. This may be accomplished with a file or by grinding and machining, although some reinforcement should be left if it does not interfere with attachment of other parts.

61. Welding magnesium alloys.—*a*. Magnesium alloys used in many fields of industry are produced in most of the commercial shapes. The metal is cast in dies, permanent and semipermanent molds, and in sand. In the wrought forms, the metal is obtainable in rolled sheet and plate, extruded bar, rod and wire, structural shapes and tubing.

b. (1) Magnesium is the base metal and constitutes 89.0 to 98.5 percent of these alloys. The alloying elements consist of aluminum, manganese, silicon, tin, and zinc in varying combinations and percentages. The composition of the alloys which have good torch and electric resistance weldability is as follows:

(*a*) For extruded forms, rolled sheet, and plate either 1.5 percent manganese and 98.5 percent magnesium or 3.0 percent aluminum, 0.2 percent manganese, 1.0 percent zinc, and 95.8 percent magnesium.

(*b*) For sand castings either 6.0 percent aluminum, 0.2 percent manganese, 3.0 percent zinc, and 90.8 percent magnesium or 1.5 percent manganese and 98.5 percent magnesium.

(2) These alloys are being used for moderately stressed aircraft parts, such as oil tanks, instrument brackets, and the framework for cockpit inclosure in some airplanes.

c. The oxyacetylene process of welding is readily applicable for welding these alloys when using a special flux and a welding rod of approximately the same composition as the metal.

(1) The flame must be carefully adjusted to neutral and checked often to avoid an oxidizing flame which must never be used.

(2) Flux is used to prevent oxidation of the metal during the welding operation. Without the aid of flux, the metal will ignite at the welding temperature and burn to an oxide. Dow Chemical Co. No. 45

and American Magnesium Co. No. 4 are the types of flux recommended. These fluxes are obtained in the form of dry powder, then mixed with clean water into a paste for application to the metal. The flux paste may be mixed and kept in glass or porcelain containers. Brass, copper, or iron containers must not be used. The flux paste is applied by brushing a thin film on the edges of the metal at the joint and on the welding rod. This flux is highly corrosive to the metal, and only the minimum amount that will give adequate protection to the molten metal should be used.

(3) No joint should be used which will trap the flux so that the joint cannot be thoroughly cleaned of the flux after welding. Butt joints only are recommended for these alloys. For welding thin gage sheet (0.040 inch and under), the flanged butt joint is preferable. The edges to be welded are bent up 1/16 to 1/8 inch and are melted down completely during the welding operation in order to prevent any flux inclusion. When welding thicknesses of 0.040 to 0.125 inch, the edges are left square and spaced about 1/16 inch apart when setting up the joint for welding. With thicknesses greater than 0.125 inch, the edges to be welded should be beveled to 45°. Welding thicknesses greater than 3/8 inch are not generally recommended, due to the difficulty of completely cleaning out the flux.

(4) These alloys must be carefully cleaned before welding. Dirt, grease, and oil may be removed with unleaded gasoline, carbon tetrachloride, or alkaline metal cleaners. The area immediately surrounding the weld should be cleaned to bright metal with a wire brush or steel wool.

(5) After the parts have been thoroughly cleaned and fitted, they should be preheated to 500° or 600° F. and the flux applied to the edges of the joint, on both top and bottom sides. The joint edges are then tacked at intervals of 1/2 to 3 inches, depending upon the shape and thickness of the metal, after which the tacks are fluxed and the seam welded. In order to reduce expansion and contraction strains the joints should be welded with as few stops as possible. By coating the welding rod with flux over its entire length the need for frequent stopping will be reduced. The size of the torch tip to use depends upon the metal thickness; it should be large enough to permit adjusting the gases to give a soft neutral flame and still have sufficient volume to keep the weld steadily progressing, once it is started. A strong harsh flame should be avoided. After the weld is started, the torch head should be tilted back to an angle of approximately 30° with the work and the forehand technique of welding employed. Castings of heavy cross-section and cored castings should be preheated in a pyrometer controlled furnace to 600° to 750° F. These castings should

be well protected from drafts with asbestos paper during the welding operation, in order to maintain an even temperature throughout the casting. After all welding is completed, the casting must be returned to the furnace and reheated to the preheat temperature, then cooled slowly, preferably in the furnace.

(6) Immediately upon cooling to a handling temperature, all traces of welding flux must be removed. Washing the weld area with hot water and a stiff bristle brush should be continued until the surface is perfectly clean. The welded part should then be immersed for 2 or 3 minutes in a hot (120° to 150° F.) chrome-pickle solution consisting of sodium bichromate, 1/5 pound; concentrated nitric acid, 1½ pints; and sufficient water to make 1 gallon. Aluminum tanks are used for this solution. After this treatment, the weld should be rinsed in cold and hot water. If the casting is too large to immerse in the solution, the casting should be heated to 150° F., and the hot solution generously swabbed over the weld, followed at once with a thorough rinse. This treatment should be repeated where the weld is subsequently ground or machined off, as minute particles of included flux may be exposed, which would exert a definite corrosive influence if allowed to remain.

Section IX

WELDING NICKEL ALLOYS

Paragraph

62. Welding Inconel.—*a.* This metal is an alloy containing approximately 75 percent nickel, 12 to 15 percent chromium, 9 percent iron, and small percentages of carbon, copper, manganese, and silicon. Inconel in the wrought condition is produced in the form of bar, plate, sheet, strip, wire, and seamless or welded tubing.

b. Inconel in the form of sheet, strip, and tube is used for aircraft engine exhaust systems because of its high resistance to corrosion and fatigue at elevated temperatures. It is workable in the cold or hot condition but should be annealed for deep forming and severe bending operations.

c. This metal is weldable by all common methods and may also be brazed, silver soldered, or soft soldered. The melting point is approximately 2,540° F., and the expansion coefficient between the temperatures of 100° and 1,400° F. is 0.00000896 inch per ° F. for each inch of length.

d. When welding by the fusion method using either the arc or gas flame, a welding flux must be used. In arc welding, the filler rod is heavily coated with the flux, while in gas welding, this flux is mixed with clean water to form a paste which is applied to both the filler rod and metal edges.

e. The filler rods for both electric arc and gas welding are of the same composition as the base metal and are obtainable in sizes suitable for welding the various thicknesses of metal. When welding with the electric arc, careful manipulation is necessary to obtain proper fusion between the electrode weld metal and base metal.

f. When gas welding this metal, careful attention must be given to the adjustment of the flame. It should be carburizing instead of neutral with the brush-like second cone about 1½ times the length of the central or first cone. The flame should be manipulated with this second or brush cone touching the metal. For light gages, the forehand torch technique is used, with the torch head tilted back about 45° to the work. The hot weld metal should not be stirred or puddled, and the rod must be added by holding the end in the melting base metal, allowing it to flow into the weld.

g. Butt welds may be made in sheet with either a rigid or open type of joint.

(1) When using the open joint, the edges must be spaced apart at a slight taper to prevent heat distortion. When welding sheet up to 0.0625 inch in thickness, this spacing should increase at the rate of ¼ inch per foot of seam length with an initial separation equal to the thickness of the metal. After the weld is started, it should be completed without interruption if possible, although in case it must be stopped midway in the seam the weld should be heated to a bright red for approximately 1 inch before being started again.

(2) When welding a rigid type butt joint, the edges should be set up parallel and separated a distance equal to the metal thickness. The seam may then be tack welded at regular intervals of approximately 2 inches. After tacking, a small amount of flux should be applied to each tack and the joint completed from the end opposite the starting point.

h. Butt joints in tubing should be made with the same technique as used in welding sheet stock. The parts are set up with the ends separated a distance equal to the tube wall thickness and tack welded at four equidistant points on the circumference. After tacking, flux should be applied and the joints completed. More frequent tacking will be found necessary in diameters above 2 inches.

i. Butt joints in either sheet or tubing should have full penetration with a slight bead on the under side. The top reinforcement should be approximately equal to the metal thickness and wide enough to give good fusion of both edges of the base metal.

j. Fillet welds for either lap or tee joints can be made successfully in this metal, but precautions must be taken to prevent the weld from

cracking or pulling out as the metal is weak and brittle at its solidification temperature. When welding fittings near the end of sheet or tubing, the metal should be heated to a bright red and this temperature extended to the edge before starting the weld. This portion should also be reheated after the weld is completed to reduce stresses and prevent buckling and cracking of the metal.

k. Jigs should be used for all types of joints wherever possible. A copper backing plate is recommended for butt welds, and this plate should be grooved to a depth of $\frac{1}{32}$ inch to allow for full penetration. The metal must be clamped in the jig just tight enough to hold the edges in alinement but not so tight as to restrain normal contraction.

l. The welding of Inconel should be done where ventilation is good, as the fumes from the melting flux are poisonous and should not be breathed by the operator.

63. Welding Monel metal.—*a.* This metal is an alloy composed of 60 to 67 percent nickel, 23 to 30 percent copper, and small percentages of carbon, iron, manganese, and silicon. The alloy is produced in the form of wrought bar, sheet, tube, and wire and is also used in castings for special purposes. This metal is strong, tough, and ductile, as well as being highly resistant to corrosion in the presence of many acids and alkalies.

b. Monel metal is weldable by means of practically all of the welding processes. It can also be brazed, silver soldered, and soft soldered as readily as the common steels. The melting point is approximately 2,480° F., and the heat expansion coefficient is 0.0000078 inch per °F. for each inch of length.

c. A flux is required for welding by all fusion methods to protect the hot metal against oxidation. This flux also dissolves any oxides that exist and floats them out of the hot metal to produce a nonporous weld. For arc welding, the welding rod is coated with the flux, while for gas welding the flux is mixed with hot water to form a thin paste which is painted on the base metal edges and welding rod.

d. The filler rod for both electric arc and gas welding is the same composition as the base metal. In the absence of gas welding rod, a strip cut from Monel sheet may be substituted for this purpose.

e. When welding by the oxyacetylene process the flame should be slightly reducing or carburizing, and in making this adjustment a slight feather extending about $\frac{1}{8}$ inch from the tip of the central cone is considered satisfactory.

f. Sheet stock should be welded in a jig in order to keep the edges in alinement and reduce buckling. The backing plate or bar of the

jig should be recessed in the same manner as that used for welding Inconel.

g. Sheet 0.0625 inch or under should be flanged for butt joints when the welding is to be done with a flame. These flanges should be bent up at an 80° angle for about 1/16 inch so that their edges when assembled will come together and give an angle on the under side of approximately 20°. In welding joints prepared in this way, a thin flux is applied to the flanges, and the seam is tack welded at intervals of 2 to 4 inches in order to hold the edges at an even height. The flanges are then melted down to make the weld.

h. Sheets heavier than 1/16 inch should be beveled, and in order to prevent overlapping of the edges caused by expansion and contraction they should be separated about 1/32 inch at the end where the weld is to start. This separation should increase at the rate of 3/8 inch per foot of seam length. When using a jig, the plates should be clamped in such a manner as to prevent the contraction from being restrained.

i. When welding plate, bars, or castings, with thick cross section, the bead should be built up to its full height as the weld progresses. Welds built up in layers will have an oxide coating separating the weld metal which is detrimental to the strength of the joint. When particles of oxides or other impurities are imbedded in the weld metal, they must be floated out by melting beneath them. The seam should be built up well above the surface in order that the oxide film and other impurities may be ground or machined off, leaving a sound, clean weld.

j. Monel metal castings should be preheated before welding. This precaution will prevent distortion and the development of additional breaks due to expansion and contraction. The preheating should be done in a furnace and the casting brought slowly and evenly to a dull red heat. Broken parts should be beveled and lined up before the heating is started. When the preheating temperature is reached, the casting should be covered with asbestos sheeting, allowing an opening only large enough to give access to the break. In this way the weld can be made without exposing a large part of the casting to the air. After the weld is completed, the casting should be covered and permitted to cool in the furnace.

Section X

WELDING COPPER AND COPPER ALLOYS

64. Welding copper.—*a.* Commercially pure copper is available in two forms. The first or electrolyte grade is produced by an electroplating process whereby the copper is deposited at the cathode in an acid plating solution. Copper in this form contains a small amount of cuprous oxide. A continued refining process removes the oxide to form the second grade, known as deoxidized copper. Either of these forms work-hardens to a considerable extent during cold drawing and forming operations and may be annealed by cooling from high temperatures. Copper does not oxidize readily and is resistant to alkalies and a great many acids. The tube form is used for aircraft fuel, oil, and water lines and is supplied in the annealed condition.

b. Copper may be welded either by means of the carbon arc or the oxyacetylene flame, although this is often found unnecessary as silver or soft solders may be readily used for making joints and connections.

(1) Welding of electrolytic copper is not often recommended as the cuprous oxides concentrate along the grain boundaries of the base metal and weld metal, reducing its strength approximately 50 percent.

(2) Fusion welds, made in deoxidized copper, will develop approximately the full strength of the base metal.

(3) If the grade of copper is not known, it is advisable to braze or silver solder rather than weld by the fusion method. When the work is carefully done, the brazing material or silver solder will melt and alloy with the copper at a temperature much lower than that required for welding.

c. When welding sheet or plate copper the plain butt joint is preferable, and sheet up to ⅛ inch in thickness may be welded with square edges. When the thickness exceeds ⅛ inch, the edges should be beveled to an angle of 60° to 90° in order to obtain penetration without spreading the fusion zone over a wide area.

d. The volume of heat necessary for gas welding copper is approximately twice that required for steel of a similar thickness. For this reason, the tip should be one or two sizes larger than the one recommended for steel. The flame should be slightly oxidizing as copper has the property of absorbing carbon monoxide gases liberated from a reducing flame, resulting in an extremely porous weld. It is always

advisable to back the seam up on the under side to prevent uneven penetration, and asbestos paper which has been heated to exclude the gases may be used for this purpose. The metal on each side of the weld should also be covered for ½ to ¾ of an inch to prevent radiation of heat into the atmosphere and allow the molten metal in the weld to solidify slowly.

e. The technique for welding copper with the oxyacetylene flames may be outlined as follows:

(1) Apply the torch along the seam for about 3 inches to bring the metal to a full red heat.

(2) Start the weld ¼ inch in from the outer edge; establish fusion at this point and return to the edge, adding filler rod.

(3) Drop the angle of the torch to approximately 65° and proceed at a uniform speed, keeping the end of the filler rod in the pool of melting metal and manipulating the flame so that the melting metal is covered at all times with the outer flame envelope.

(4) When the metal ceases to flow freely, raise the filler rod and again bring the metal to a red heat for 2 or 3 inches along the seam; then start the weld where it was left off and continue in this manner until completed.

(5) When possible, preheat with a separate heating unit as this makes the welding operation much easier to perform, and the weld is usually less porous than one made by preheating and welding with the same flame.

65. Welding brass.—*a.* Brass in its simplest form is an alloy of copper and zinc, although other metallic elements are often added to improve its characteristics. Naval brass is one of the best of these alloys and consists of 62 percent copper, 0.5–1.5 percent tin, 0.0–0.10 percent iron, 0.20 percent lead, and the remainder zinc. It is used for a great many purposes, especially where high strength, toughness, and resistance to corrosion are essential. This alloy is available in the bar, plate, rod, sheet, and strip form and in the soft, half hard, and hard condition of temper.

b. All grades of brass are weldable with the oxyacetylene flame, and some can be welded with the carbon arc. The metallic arc process is, however, generally considered unsatisfactory. When welding with the oxyacetylene torch, a slight excess of oxygen should be used. These metals require careful application of heat at their melting point and should not be held in a melting state longer than is necessary for complete fusion, as the zinc content of brass has a tendency to burn or oxidize readily at high temperatures.

c. A good flux is essential in welding all grades of brass. This flux on melting forms a film over the hot metal, protecting it from

the air and other gases, as well as cleaning it of oxides formed during the welding process. Any good commercial brazing and welding flux is satisfactory, and borax diluted with boric acid or sodium carbonate may be used. Its application is made either by dipping the hot end of the rod in the dry flux or disolving the flux in hot water and painting it on the rod.

d. The filler rod used for the oxyacetylene welding of these alloys may be of the same approximate composition as the base metal, although better results are obtained with a rod having a lower melting point. In this case, the parts being welded need not be melted, as the low melting point alloy will unite with the base metal readily at a temperature just below its melting point. Brass welding rods meeting the above requirements are available under the trade names of Tobin bronze and manganese bronze.

e. Brass may be welded, using the same type of joints recommended for other metals. Bars, sheets, and castings, of heavy cross section, must be beveled mechanically, as cutting with the torch or melting to a bevel is impractical due to the loss of the zinc content that would result. Preheating of heavy parts is essential as it reduces the amount of heat required to do the actual welding. This precaution also lessens the possibility of warped and strained parts.

66. Welding bronze.—*a.* There are two general classes of bronze, each of which may be found in several grades: true or gun bronze and commercial bronze, the latter being more commonly used in the commercial field.

(1) True bronze is an alloy containing 90 percent copper and 10 percent tin. It is a fairly tough and hard metal, having excellent wearing qualities and high corrosion resistance.

(2) Commercial bronze has a wide range of uses and the various forms may be described as follows:

(*a*) *Aluminum bronze.*—This alloy, in the grade generally used, contains 84 to 93 percent copper, 7 to 10 percent aluminum, and 4 percent iron, with the addition of small amounts of other metals, including nickel, tin, and manganese. Aluminum bronze is available in bar, rod, sheet, strip, etc., and is used for bearings and other parts requiring high strength and corrosive resistant qualities.

(*b*) *Manganese bronze.*—Manganese bronze contains 57 to 60 percent copper, 0.05 to 1.5 percent tin, 0.8 to 2 percent iron, 0.50 percent manganese, 0.25 percent aluminum, and the remainder zinc. This metal is available as bars, rods, plates, forgings, etc. Due to its strength and corrosive resistant qualities, it is used extensively for marine purposes.

(*c*) *Phosphor bronze.*—This metal is an alloy containing 89 to 94 percent copper, 3.5 to 9 percent tin, 0.30 percent zinc, 0.05 to 0.10 percent lead, 0.05 to 0.10 percent iron, and 0.05 to 0.35 percent phosphorus. It is obtainable in the bar, plate, rod, sheet, strip, and wire forms, and is used for such parts as bearings, electrical contacts, springs, etc., in airplane engines.

b. Bronze may be welded in much the same manner as brass. Practically all of the different mixtures can be welded satisfactorily with the oxyacetylene flame and some can be welded with the carbon arc. The filler rod used for gas welding operations should be of the same approximate composition as the alloy being welded.

c. As in brass welding, all grades of bronze require the use of flux and with the exception of aluminum bronze this flux may be the same material as used for brass. Aluminum bronze requires a more energetic flux, due to the fact that its oxides have a higher melting point than the base metal. A mixture composed of equal parts of brass and aluminum welding flux, dissolved in water and applied to the rod, will be found satisfactory.

d. The welding flame should be adjusted to give a slight excess of oxygen for all alloys except aluminum bronze which requires a strictly neutral flame.

Section XI

BRAZING AND SILVER SOLDERING

67. General.—Brazing and silver soldering are methods of bonding metals where strength is not the important factor. In either of these processes, a low melting point alloy is used to sweat or bond the joint together without actually fusing the base metal. The term "brazing" is generally understood to mean the joining of metals with a film of brass, while "silver soldering" indicates that a silver alloy is the medium used.

68. Brazing.—*a.* Brazing may be used to join copper, high melting point brass, bronze, Monel metal, plain carbon steels, and some of the alloy steels. The high chromium stainless steels do not braze satisfactorily.

b. The brazing mixture, generally used for metals having a melting point of 1,750° F. or more, is an alloy of copper, tin, and zinc, which has a melting point of approximately 1,625° F. In case the

parts require heat treating, an alloy of copper and zinc which melts at 1,832° F. is used. This alloy consists of 80 percent copper and 20 percent zinc. An alloy of 50 percent copper and 50 percent zinc is sometimes used for copper and the low melting point brasses. This alloy has a melting point of 1,560° F. and is used in a granulated form, referred to as brazing spelter.

c. A flux is required for all brazing operations, regardless of the metals being joined. A mixture made from equal parts of borax and boric acid may be used for copper, brass, bronze, and Monel metal, while a mixture of three parts of boric acid and one part of borax will be found satisfactory for steel. Several good, ready mixed, commercial fluxes are also available. Application of the flux may be made in the powder form or dissolved in hot water to a highly saturated solution.

d. The strongest type of brazed joint is one in which the width of the seam is greater than the metal thickness. A lap joint in thin sheet metals, having a seam width of 4 to 6 times the metal thickness, will develop a strength approximately equal to the base metal. Butt joints may be used for moderately stressed assemblies, although they must be reinforced with filler metal. For brazing, the metal must be cleaned to a bright surface in the joint. A hot, 10 or 15 percent solution of caustic soda and water, followed by a hot water rinse, or a mixture of equal parts of carbon tetrachloride and naphtha will eliminate grease and oil efficiently, while a sand blast is preferable for the removal of oxide and scale. A grinding wheel, wire buff, or file may be used for this purpose in case a sand blast is not available. After cleaning, the joint should not be handled as any trace of oil or grease will cause trouble when brazing.

e. The brazing process may be accomplished by means of a blowpipe flame by heating the parts in a furnace or by submerging them in a molten bath of the brazing mixture.

(1) *Blowpipe brazing.*—The oxyacetylene or Bunsen burner flame may be used for this process. When using the oxyacetylene flame, a larger tip is required than for welding the same metal. The flame should be neutral and the outer flame envelope used to supply the heat. The tip of the central cone should be held ¼ to ⅜ of an inch from the metal surface at the joint. Flux may be applied either by dipping the hot end of rod in the dry powder or by coating the rod with a flux solution. When starting to braze, the joint should be brought to a full red heat so that the flux will melt and flow when applied. Sufficient brazing metal should be added to sweat through the joint, and care must be taken to prevent overheating either the

base metal or brazing metal. The presence of a blue vapor indicates an excess of temperature.

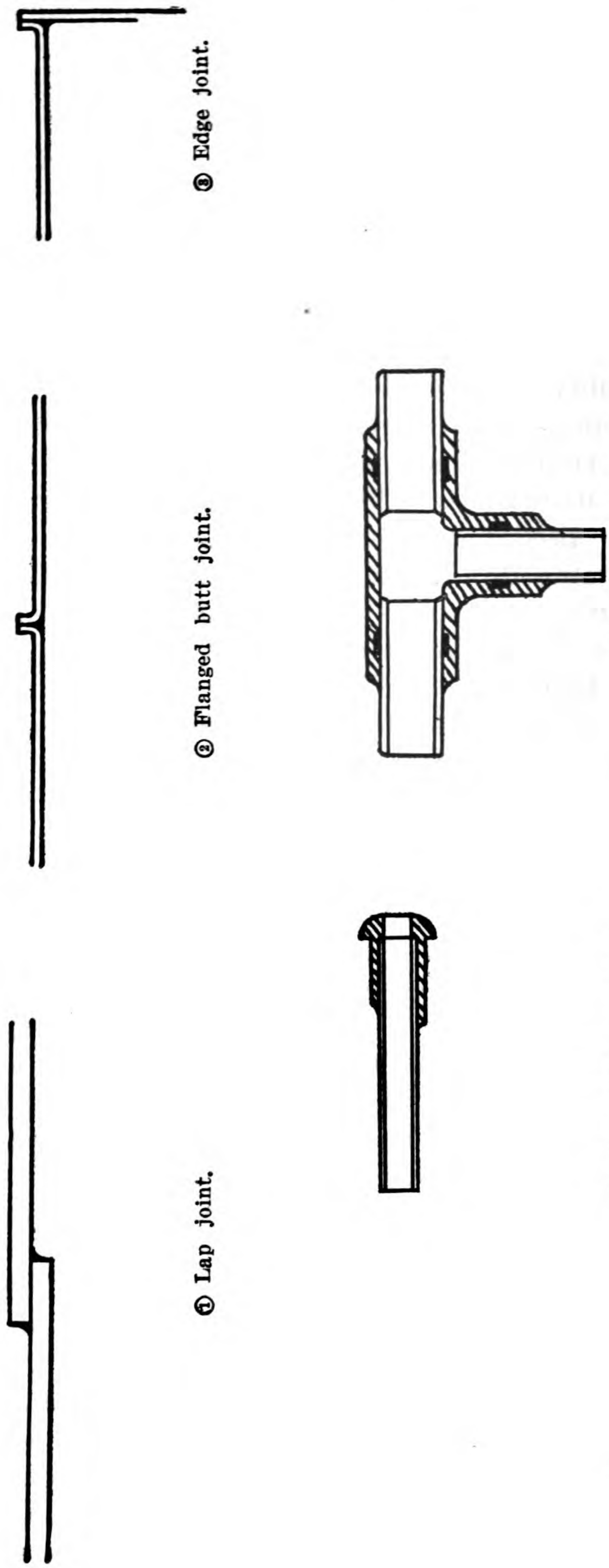
(2) *Furnace brazing.*—Brazing in this manner is accomplished by setting up the work with both the flux and brazing metal placed in the joint. The furnace temperature is then raised to a point where the brazing alloy will flow and adhere to the metal.

(3) *Dip brazing.*—This process is used to a great extent in production work. The parts are set up and electric spot welded or riveted to hold them in proper alinement, then preheated to between 800° and 1,000° F. At this temperature the parts are passed through two baths of molten flux which are heated to 1,300° and 1,600° F. respectively. After being allowed to remain in each bath for 5 minutes, the parts are transferred to a molten brazing mixture which has 2 or 3 inches of flux on its surface. The assembly is held in this bath for 3 minutes, then is raised and lowered several times to cause it to pass through the cleaning flux on top of the brazing metal. After the brazing operation is completed, the parts should be cooled slowly and evenly to prevent contraction strains.

69. Silver soldering.—*a.* Silver solder is extensively used for joining copper and its alloys, Monel metal, nickel, and silver, as well as various combinations of these metals. It is also used to some extent for joining thin steel parts, such as band saw, blades, etc.

b. Silver solder is obtainable in several different grades, with a silver content ranging from 14.5 to 66 percent and having melting points from 1,160° to 1,600° F. These solders are furnished in rod, strip, and wire form, the strip and wire forms being the standard shapes. The strip form is generally used for fixed set-ups where the solder can be placed in the joint before heat is applied. The wire form is used principally for joints where it is preferable to apply the solder after heating. It is also used commercially in the manufacture of brass and bronze pipe fittings and in the installation of copper and brass high pressure pipe lines. Assemblies of this kind are made by placing a ring of the solder in the joint, before applying the heating flame, as shown in figure 66⑤.

c. Flux is necessary for all silver soldering. The flux acts as a cleansing agent and prevents oxidation of the base metal during the soldering operation. A flux especially prepared for this work is obtainable from the Handy-Harman Company, manufacturers of silver solders. This flux is furnished in a paste form and is suitable for all work in which silver solder is used. It begins to melt at 800° F., becomes fluid at 1,100°, and remains stable up to 1,600°. A mixture of 12 parts of borax and 1 part of boric acid may be used as a flux for the high melting point solders, in case a prepared flux is not



① Lap joint.
② Flanged butt joint.
③ Edge joint.
④ Flanged tube connection.
⑤ Tee type tube assembly.

FIGURE 66.—Recommended joints for silver soldering.

available. The flux must melt at a slightly lower temperature than the solder, and the temperature at which the flux begins to flow freely may be used as an indication of the proper temperature for applying the solder.

d. The metal must be perfectly clean at the joint in order to obtain a good union of the base metal with the silver solder. All dirt, grease, oil, oxide, paint, etc., must be removed and the metal made bright. The cleaning preparation for silver soldering is the same as described for brazing. The joint best suited for all stresses is one in which the metal can be formed to give a width of seam that is greater than the metal thickness and figure 66 illustrates several recommended types. The amount of lap depends upon the strength required. Four to six times the metal thickness for sheet and small diameter tubing will give a strength equal to the base metal in the heated zone.

e. The oxyacetylene flame is suitable for silver soldering all thicknesses of metal, while the acetylene and air flame may only be used for the light gages. When using the oxyacetylene flame, it should be mild and may either be adjusted to neutral or given a very slight excess of acetylene. During the preheating and application of the solder, the tip of the central cone should be held about ½ inch from the work and kept in motion to avoid overheating. On large surfaces, the metal should be preheated well away from the joint, especially when soldering metals which have a high thermal conductivity. Care must be taken in soldering metals of different thicknesses or unequal heat conductivity, as it is necessary that both parts reach the soldering temperature at the same time. When this temperature is reached, the solder should be applied to the surface of the under or inner part at the edge of the seam, while the flame is directed over the entire seam and kept in motion in order to maintain an even temperature.

70. Cleaning and finishing brazed and soldered joints.—*a.* After a joint has been made by means of brazing or silver soldering, the flux must be removed as it is often corrosive to the metals and will prevent the adherence of paint and other protective coatings.

(1) Flux may be removed from all nonferrous metals by treatment in a solution made by adding 1 fluid ounce of sulfuric acid and 1.5 ounces of sodium bichromate to 1 gallon of water.

(2) Flux may be removed from ferrous metals by boiling them in a 10 to 15 percent solution of caustic soda for 30 minutes.

(3) In either case the treatment must be followed by a thorough rinse in clean water.

b. (1) After brazing or silver soldering, the base metal is usually discolored in the area affected by the heat. This is particularly true of

copper and brass, and if it is desired to restore these metals to their original finish they should be immersed in a "bright dip" followed by thorough rinsing in clean running water. An effective bright dip may be made by mixing 68 fluid ounces of sulfuric acid, 20 fluid ounces of nitric acid, 0.12 fluid ounc of hydrochloric acid, and 40 fluid ounces of water.

(2) Scale, caused by heating steel parts may best be removed by means of a light sand blast.

Section XII

HARD SURFACING WITH SPECIAL ALLOYS

71. General.—*a.* The term "hard surfacing" refers to the process of applying an extremely hard alloy to the surface of a softer metal to increase its resistance to abrasion. This process can be applied to new parts before their use, or to worn parts, to restore them to their former condition.

b. Treatment in this manner results in fewer replacements of parts and a general increase in operating efficiency of the equipment so treated. Experiments show that wearing surfaces treated with these special metals will outwear the common steels 2 to 25 times, depending on the type of hard facing alloy used and the service to which the part is subjected.

c. In most cases, the hard facing alloys can be applied by means of either the oxyacetylene or electric arc process, although the arc is preferable for some metals. The following classification affords a ready means of determining which of the metals can be hard faced, and gives the process which has been found to be the best for the application.

(1) *Carbon steels.*—All the straight or plain carbon steels can be hard faced by means of either the oxyacetylene or electric arc process. Heat treatment is necessary before and after hard facing the high carbon steels due to their extreme hardness.

(2) *Low grade alloy steels.*—Hard facing alloys can be applied to the low grade alloy steels in the same manner as described for the carbon steels. As in the case of high carbon steel, heat treatment is sometimes required after the facing operation.

(3) *High speed steels.*—Hard facing of the high speed steels is not generally recommended. This is due to the fact that shrinkage strains usually develop cracks or checks in the hard faced piece, rendering it valueless in a good many instances regardless of heat treatment.

(4) *Manganese steel.*—The metallic arc is recommended for all applications of hard surfacing materials to manganese steels.

(5) *Stainless steels.*—This group which includes the high chromium and chromium-nickel steels may be readily hard surfaced by means of either the arc or oxyacetylene process.

(6) *Cast iron.*—Cast iron may be hard surfaced by means of either the arc or oxyacetylene process, although the procedure is somewhat different from that of steel, due to its lower melting point.

(7) *Monel metal.*—The oxyacetylene process is preferable for applying hard surfacing materials to this alloy.

(8) *Brass and bronze.*—These alloys cannot usually be hard surfaced because of their low melting point. It is, however, possible to apply Stellite to heavy sections, with the electric arc, after the parts have been brought to a red heat.

(9) *Copper.*—Copper can be hard surfaced with Stellite in the same manner as described for brass and bronze. The application is, however, quite difficult because of its low melting point and high heat conductivity.

(10) *Aluminum.*—Aluminum or its alloys cannot be hard surfaced.

72. Hard surfacing materials.—*a.* Hard surfacing materials are, in general, divided into three classes. The first group consists of the alloys having an iron base and containing such elements as chromium, tungsten, manganese, and silicon. Small quantities of cobalt and nickel are also included in some cases. The second group consists of the nonferrous alloys, such as chromium and cobalt, with a small percentage of tungsten or molybdenum. The third group is known as the diamond substitutes and consists of alloys of tungsten carbide.

b. All of these materials are obtainable under various trade names and in forms suitable for application with either the electric arc or oxyacetylene process of welding. The Haynes Stellite Corporation markets these materials under the following trade names:

(1) *Iron base alloy*, "*Haschrome.*"—This metal is a tough, self-hardening chromium-manganese-iron alloy used for hard surfacing parts subjected to moderate abrasive wear or severe impact. It is also used as a filling or base metal under the more wear-resistant

alloys, and as a binder for the diamond substitute. This metal is considerably lower in price than the nonferrous alloys, and when badly worn units are being reclaimed it is considered economical as an undercoat.

(2) *Nonferrous alloy, "Stellite."*—This alloy is manufactured in five standard grades in the form of tool bits, bar stock, milling cutter blades, boring and reaming blades, valves, dies, special castings, bushings, and welding rods. A system of numbers is employed for identification, and grades 1 and 12 are used mainly in the form of welding rod for hard facing applications. The grade 1 rod is obtainable in 1/8, 3/16, 1/4, and 5/16 inch diameters, while the grade 12 is furnished in 1/4, 5/16, and 3/8 inch diameters.

(3) *Tungsten carbide alloy, "Haystellite."*—This alloy is available in rectangular, half round, and other shapes ranging in size from 1/4 by 5/16 by 3/4 inch to 1/8 by 1/4 by 3/8 inch. Rods of this material consist of crushed tungsten carbide of various screen sizes uniformly distributed in a binding material and are referred to as composite rods. Tungsten carbide is used where the utmost resistance to abrasion is desired.

73. Preparation of metal parts for application of hard surfacing materials.—It is very important that all scale, rust, or other foreign substances be removed from the area to be hard faced. This should be accomplished by grinding, machining, or chipping, although if these facilities are not available, the surface may be cleaned by filing, sand blasting, or wire brushing. The latter methods should be avoided, if possible, as they often leave foreign material which must be floated to the surface during the hard facing operation. If recesses are cut in the surfaces to receive Stellite, all internal corners should be well rounded. Parts that require preheating may be brought to the required temperature by means of the oxyacetylene flame or a furnace.

74. Hard facing with Stellite.—*a.* The oxyacetylene flame is suitable for the application of Stellite to the majority of metals and is preferable in some cases, especially when it is desired not to change or dilute the applied alloy with the base metal.

(1) *Application of Stellite to steel.*—The flame must contain an excess of acetylene and should be adjusted so that the second, brush-like cone, is approximately double the length of the inner or first cone. Unless this type of flame is used, the deposited metal tends to pile up instead of spreading freely.

(*a*) The procedure for applying Stellite to steel with the oxyacetylene flame, consists of heating a small section of the surface

to a sweating temperature. The end of the Stellite rod is then brought into the flame and allowed to melt and spread over the sweating area. If conditions are correct, the Stellite will spread immediately and flow over the surface like solder on a properly heated and tinned surface. The operation is then continued by adding Stellite and spreading it in the direction desired. The metal should not be stirred or spread with the rod, but made to flow with the flame. The torch head should be held at approximately 45° to the surface, with the flame pointing in the direction of flow. During the operation, if any particles of rust or scale are encountered on the surface of the base metal, it is necessary that they be floated to the surface. If they are allowed to remain and are covered by the deposit, they will, in most cases, develop blowholes. It is preferable to build the coating up to the desired thickness in one operation and, in case the part is badly worn, it should be built up with ordinary steel before hard facing. In most cases, the Stellite coating will range from 1/16 inch to 1/4 inch in thickness.

(*b*) Steels, which are in the hardened condition, should be annealed before the Stellite is applied. This is necessary to prevent checking, and rehardening may be accomplished, after the hard facing is completed by quenching in oil.

(2) *Application of Stellite to cast iron.*—Cast iron does not sweat like steel and, because of the high percentage of free graphite carbon, the Stellite does not flow as readily on this metal. The flame must again have an excess of acetylene, with the brushlike second cone reduced to about half the length required for steel. The surface crust will usually have to be broken with the end of the rod and a cast iron flux is necessary in some cases. It is usually best to weld on a thin coat of Stellite and then go over it again, building it up to the required thickness. Stellite and cast iron have about the same melting point; therefore, care must be taken to prevent melting the cast iron too deeply. If the base metal is very thin, it should be backed up with wet asbestos or carbon paste to prevent collapse.

b. Metals, that are to be hard surfaced with the metallic arc, should be prepared in the same manner as described for the oxyacetylene process. Some interalloying of the surface and base metals will always occur but this condition should be kept at a minimum.

(1) When using a direct current arc, the polarity should be reversed, making the rod the positive electrode. The current strength must be reasonably high, since all Stellite rods are cast and are fairly large in cross section. The 1/4 inch rod requires 175 to 200 amperes, and the 5/16 inch rod, 225 to 300 amperes. These values depend

largely upon the base metal cross section. It is recommended that the rod be coated for best results and a satisfactory coating may be prepared by mixing equal parts of calcium carbonate (precipitated), silica flour, and either borax glass or sodium bicarbonate. The addition of shellac will serve as a binder. Should this mixture not be available, carbide sludge will give satisfactory results.

(2) When using an alternating current arc, the ¼-inch rod requires 280 amperes and the 5⁄16-inch rod 300 to 325 amperes. A long arc should be maintained for best results.

75. Building up worn surfaces with iron base alloy.—These alloys can be applied by means of either the arc or oxyacetylene process. In the use of either method, the surface should be thoroughly cleaned and preheated where necessary as in the application of Stellite.

a. When applying this metal to steel with the oxyacetylene torch, the flame should have an excess of acetylene to the extent that the white brush-shaped second cone is about equal in length to the first or inner cone. A neutral flame causes the metal to boil and produce an unsatisfactory deposit. The procedure for applying this metal is very similar to that described for Stellite. A sweating heat is the correct temperature for application, and the rod should be melted onto the sweating area and allowed to spread.

b. When surfacing cast iron, a small area should be heated almost to the melting point and the surface crust broken with the rod. A little puddling is usually necessary and a good cast iron welding flux is helpful.

c. The hardness of the deposit of this metal depends upon the amount of acetylene used in the flame and the rate of cooling. If an exceptionally hard deposit is required, a much greater excess of acetylene should be used and the part allowed to cool slowly. If the part is quenched, the deposits will be made tougher, but a certain amount of its hardness will be lost.

d. In applying this alloy with the arc, reversed polarity must be used, making the rod the positive electrode. Application of a flux will make the metal flow more readily. A very satisfactory flux may be made by mixing equal portions of sodium bicarbonate, calcium carbonate, shellac, and borax glass, with the addition of enough alcohol to bring it to the proper consistency for application to the rod by dipping or painting.

76. Hard facing with tungsten carbide.—As previously stated, this alloy is obtainable in different forms, and the procedure of application will necessarily be governed by the form used. The majority of

these types can be applied with the oxyacetylene flame although the arc is often preferable and is necessary if fusion is required.

a. When hard facing with individual pieces of tungsten carbide, the oxyacetylene process is generally used and the surface must be ground free of all scale and rust. Application is made by first tack welding the piece of tungsten carbide to the end of an iron base alloy or high strength steel rod. A small area of the base metal is then melted with the blowpipe and about ¼ of the body of the piece submerged in this molten pool. A thin coating of the filler rod metal is then flowed around the insert to bind it in place. Should accurate spacing be necessary grooves may be machined in the surface of the base metal to receive the inserts. The flame used for this process must carry a slight excess of acetylene.

b. The composite rod is applied with the oxyacetylene flame. The flame should contain a small excess of acetylene and the deposit made without penetrating too deep into the base metal. The surface of the base metal must first be brought to a molten state and the rod then melted and flowed into the melting puddle. A small amount of stirring with the rod is necessary to obtain even distribution of the deposit as this rod does not flow as freely as ordinary fillers. The base metal may be heat-treated after application of the alloy by quenching in oil to give it a harder and tougher structure.

c. Tungsten carbide, prepared for application with the metallic arc, consists of fine particles of the alloy enclosed in a steel tube. This tube or rod is used as the working electrode and the machine is set for reverse polarity. The carbon arc method of welding may also be used for the application of tungsten carbide. In this case, fine particles of the material are sprinkled on the surface and fused into the base metal by means of the arc. The preparation of the base metal for either method of application is necessarily the same as required for application with the oxyacetylene flame.

Section XIII

AIRPLANE CONSTRUCTION AND REPAIR BY WELDING

77. General.—*a.* Welding is used extensively in the manufacture and repair of airplanes. Such parts as landing gears and engine mounts are practically always fabricated in this manner, while many fuselages, control surfaces, fittings, tanks, etc., are also of welded construction. In structures that have been welded in manufacture, repairs may generally be economically made by this process. Careful workmanship, both in preparation and actual welding, is of utmost importance.

b. Many parts used in the construction of aircraft are made in such a way as to prohibit the use of welding and other applications of heat. This is due either to the type of metal involved or the heat treatment to which the part has been subjected.

(1) Airplane parts fabricated of alloy steels which are heat-treated to develop their required strength should not be welded or brazed unless the part can be reheat-treated to the original specifications. Steel parts which are usually heat-treated are landing gear struts, highly stressed fittings, standard aircraft bolts, clevice pins, and turnbuckle ends. Struts forward of the cockpit in the steel tube fuselages and engine mount members may also be heat-treated in certain instances.

(2) Steel parts that depend upon the strength developed by cold working should never be welded. The parts which come under this classification are streamline wires, cables, tie rods, and solid drawn wires.

(3) Steel parts which have brazed or soldered joints should not be welded, as the brazing or soldering mixture will penetrate the hot steel and result in an inferior weld.

(4) Aluminum alloy parts, which are used in the heat-treated state, should not be welded or soldered. The amount of heat required for these operations is sufficient to destroy the effect of the heat-treatment, and treatment after welding is not practical as the cast metal in the weld does not respond sufficiently to allow the strength to be brought to normal. Heat treatment after soldering is not satisfactory, since the aluminum solders melt at a low temperature. Joints in all heat-treated aluminum alloy structures are made by riveting and bolting or by similar mechanical means; therefore, repairs to those units and parts should be made in a similar manner. Heat-treated aluminum alloy castings which are worn or damaged to the extent that they are no longer serviceable should be replaced with new ones.

78. Cleaning of aircraft parts in preparation for welding.—Most metal airplane parts are treated with some kind of protective coating to prevent corrosion. These coatings consist of cadmium plating, enamel, paint, or varnish and must be removed from the area where brazing, soldering, or welding is to be done in order to facilitate these operations and to prevent the inclusion of the coating in the metal at the joint. There is usually some dirt, grease, or oil present that must also be removed.

a. Cadmium plating may be effectively and quickly removed without damage to the metal by immersing the edges to be welded in any of the following solutions:

(1) A mixture of 73 cubic centimeters of hydrochloric acid, 27 cubic centimeters of water, and 2 grams of antimony trioxide.

(2) A mixture of 1 pound of ammonium nitrate and 1 gallon of water.

(3) A mixture of 3 gallons of water, 7½ gallons of hydrochloric acid, and 1½ pints of ammonium nitrate.

b. Enamel, paint, or varnish may be removed from steel parts by mechanical means, such as buffing with a wire brush, sand blasting, or the application of emery cloth, etc. These coatings may also be removed with a paint and varnish solvent or by treatment with a hot 10 percent solution of caustic soda. If the latter is used, the parts should be thoroughly washed with warm or hot water to remove the solvent and residue. Rust or scale when present on steel parts must also be removed, and a sand blast is the most effective equipment for this purpose. Enamel, paint, varnish, or heavy films of oxide on aluminum and aluminum alloys may readily be removed by the application of a hot 10 percent solution of either caustic soda or tri-sodium phosphate. After treatment, the parts should be immersed in a 10

percent nitric acid solution followed with a hot water rinse to remove all traces of the chemicals, as they have a tendency to corrode the metal. Paint and varnish may also be removed by the use of a good prepared paint and varnish remover.

c. Dirt, grease, or oil may be removed from all parts with a hot caustic soda solution or a mixture of equal parts of carbon-tetrachloride and naphtha. If other cleaners are not available, unleaded gasoline will prove satisfactory and should be applied with a clean rag, saturated with just enough gasoline to remove the film.

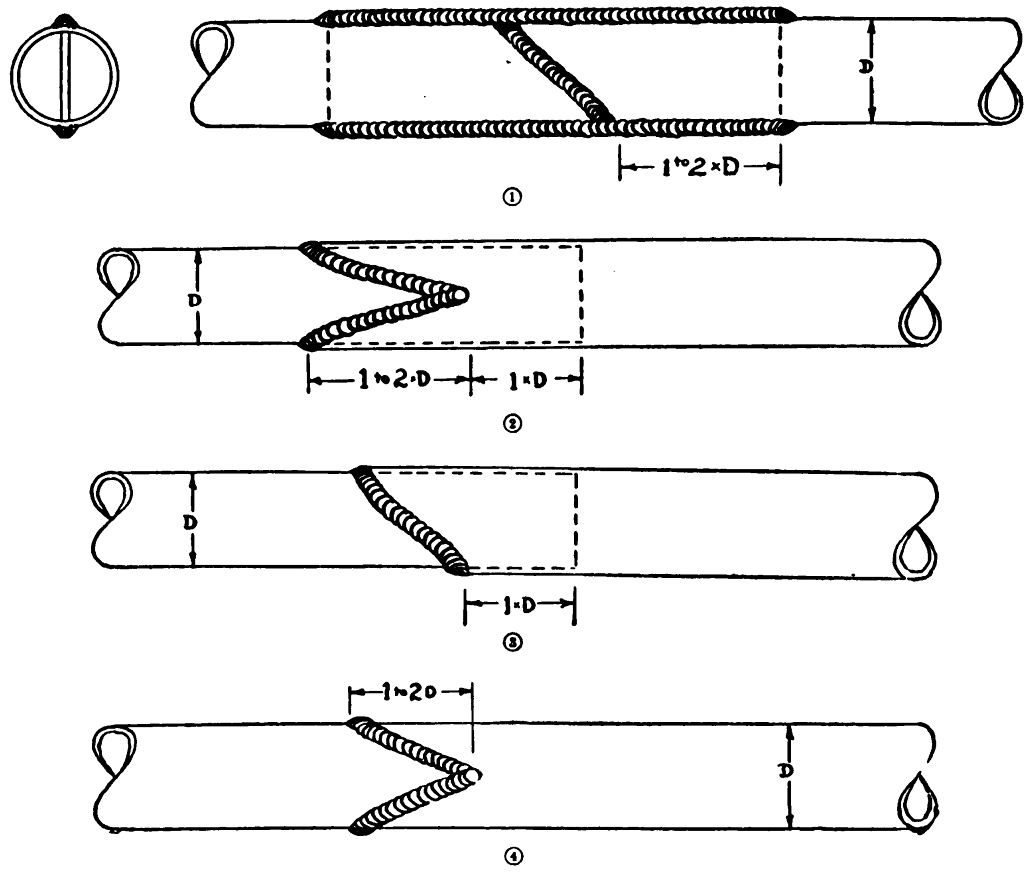


FIGURE 67.—Types of tube splices.

79. Welded splices.—*a.* Several different types of tubular splices used in the construction of steel tube structural assemblies are shown in figure 67. These joints when properly fitted and welded will develop the full strength of the tube in the annealed or normalized condition.

(1) Joint shown in figure 67① is a scarf butt splice reinforced with a steel gusset plate. This splice is sometimes used to join the ends of the circular member of a radial engine mount. The ends of the tube are prepared with a slot to receive the gusset plate which

extends from 1 to 2 diameters on each side of the weld between the tube ends. The gusset plate should be $\frac{1}{4}$ inch wider than the outside diameter of the tube and the cut for the scarf splice made at an angle of 45° or less.

(2) Joint shown in figure 67② is a fishmouth reduction splice in which the end of the telescoping tube is cut to give a fishmouth form. The length of cut measured on the outside of the tube is from 1 to 2 diameters of the smaller tube. This type of joint gives a greater length of welded seam than a butt or scarf splice and eliminates heating the tube to the welding temperature in a direct cross section. It is used to splice continuous members of steel tube fuselages and members of other units where tube splices of different diameters are required.

(3) Joint shown in figure 67③ is a scarf reduction splice in which the end of the telescoping tube is cut diagonally at an angle of 45° or less. This type of joint is used for splicing members of different diameters and is similar to the fishmouth splice, in that the tube is not heated to the welding temperature in a direct cross section.

(4) Joint shown in figure 67④ is a butt splice in which the ends of both members are cut to give a fishmouth form. This type of splice is used for both equal and unequal tube diameters. When used for the latter case, the end of the larger tube is swaged to a taper and the small tube is expanded to match it.

b. Joints in which tubular members meet at an angle are used to a great extent in airplane structures. These joints are, in general, designed so that the axis of the brace members in the joint will terminate at a common point on the axis of the main member of the assembly as shown by the center lines in figure 68. This arrangement transmits the load through the joint without imposing a tearing stress in the weld or torsional and bending stresses upon the main member. The highly stressed joints are usually reinforced with gusset plates. These gusset plates relieve some of the load stresses on the welds between the tubular members as well as increasing the rigidity of the truss. In some cases the main member and ends of the truss members are slotted, and the gussets are continued through the joint as shown in figure 68⑤. Gussets may also be set in the angles between the truss and main member as shown in ⑥. The gusset in the latter type may be made of flat stock or formed into a U shape. The U shaped gusset is generally used as it is somewhat stronger and the load through the gusset to the tube is distributed over a greater area.

c. Another method often used to reinforce joints of this type makes use of a sheet metal plate with fingers extending onto the several members in the joint. This plate is formed to fit the members and welded to each of them at its edges.

d. Tubular members which are broken, split, or otherwise damaged may be removed and a new section spliced in by means of welding.

(1) The procedure for making this type of repair requires the structure to be lined up and held in position with fixtures while

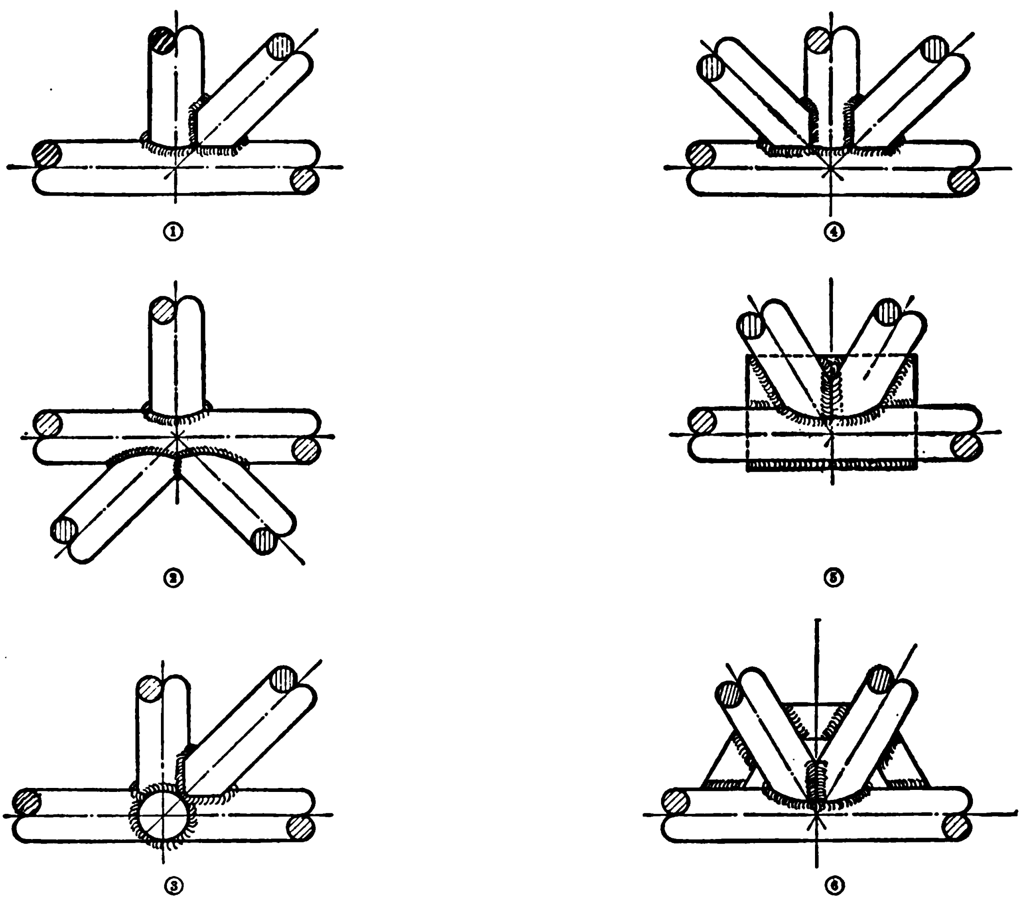


FIGURE 68.—Welded tube clusters and angle joints.

the repair is being made. These fixtures consist of an adjustable brace or jack placed between the supporting members to hold them apart. An adjustable clamp must also be placed on the outside of the members directly over and parallel to the jack to prevent the assembly from spreading apart. Figure 69 shows the jack and clamp placed in position for making such a repair.

(2) The original dimensions must be maintained in order that the structure will be in proper alinement when the repair is com-

pleted. Dimensions may be obtained from drawings of the structure or by measuring the corresponding member which is not distorted. In the latter case, the main member should be lightly prick punched, in line with the center of the brace member intersections, and the dimensions taken with trammel points and a bar. The measurements obtained in this way may be applied to the structure being repaired and the clamps used to bring the members to the required position.

(3) Several splices may be used for replacing tubular sections; however, the splice used must develop the strength of the original member.

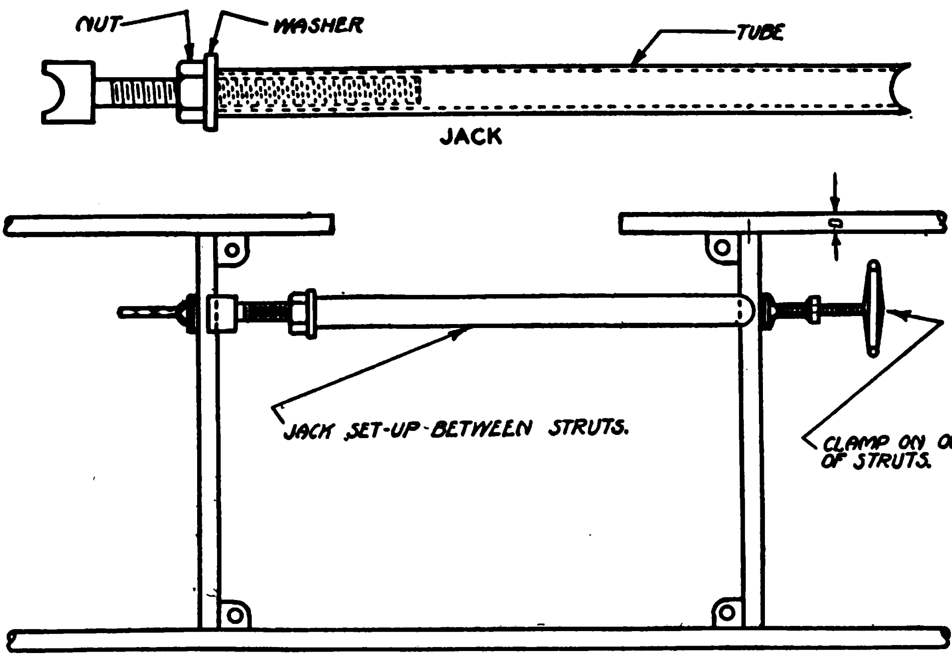


FIGURE 69.—Fixture for holding tubular structures in alinement.

(*a*) Figure 70 shows two types of outside sleeve splices which will develop the full strength of the original member under tensile or bending loads. The sleeve for either of these splices should be a fairly snug fit to the stub end of the original tube and replacement section. The ends of the fishmouth sleeve shown in figure 70① are prepared with a length of cut of 1 to 2 diameters of the tube. Two diameters are preferred and the ends of the fishmouth prongs should not be flattened or rounded. The ends of the scarf sleeve shown in ② should be cut to 45° or less and the holes for the rosette welds made ¼ inch in diameter. The procedure for assembling and welding these forms of splices should be as follows:

1. Place the adjustable brace and clamp in position to hold the structure in alinement, then remove the damaged tube

leaving a stub end remaining at the station joints at least 4 times the tube diameter.

2. Cut a new section of tubing to replace the damaged section. The tube must be of the same diameter and wall thickness as the original member.

3. Place the sleeves on the new section, locate them in position. Slip the sleeves on the stub ends of the original tube, then center as shown in the figure.

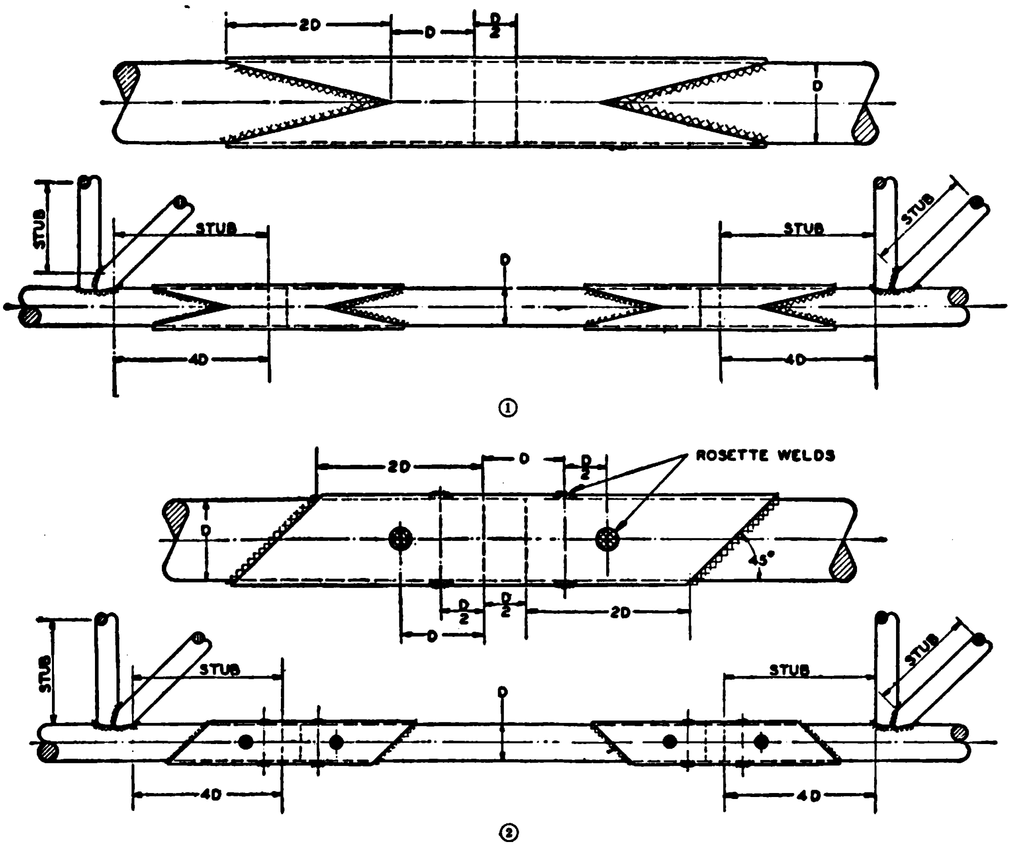


FIGURE 70.—Outside sleeve tube splices used for replacing sections of tubular members.

4. Weld both ends of one sleeve and one end of the other sleeve.

5. Permit these welds to cool, then by means of the adjustable brace and clamp, make the allowance for shrinkage of the weld. This should be about 1/16 inch.

6. Tack weld the sleeve on each side of the tube for approximately 1/4 inch.

7. Remove the brace and clamp and complete the joint, starting the finish weld at any point other than at the tack welds.

8. When using the scarf sleeve, make the rosette welds after the ends of the sleeve are finished.

(*b*) The fishmouth and scarf butt joints with internal sleeves, shown at *A* and *B*, figure 71, may be used for welding in a new section when no increase in the outside diameter of the tube is desired. Joints of this type have about the same resistance to bending as the outside sleeve splices and will develop the full strength of the tube, although they are more difficult to set up. The sleeves for these splices should have a wall thickness equal to, or greater than, the member being repaired and should be 5 to 6 times the tube diameter in length. Holes ¼ inch in

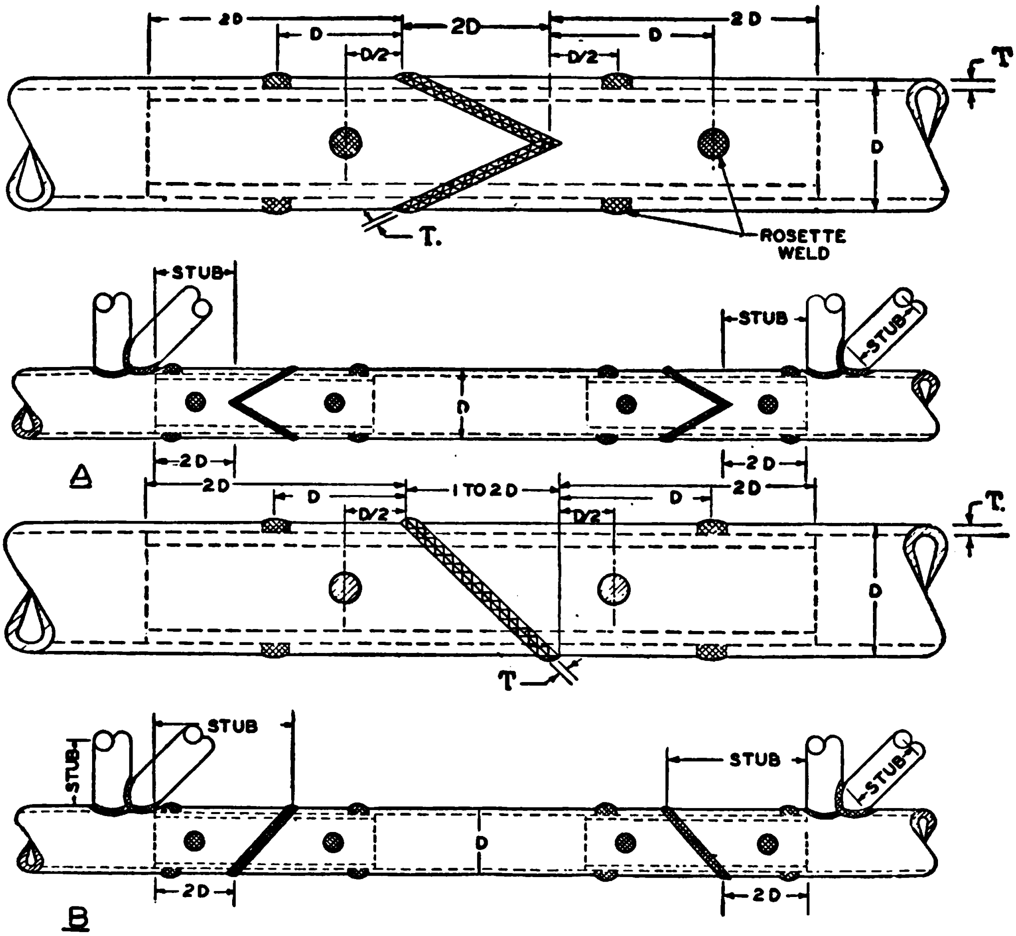


FIGURE 71.—Fishmouth and scarf butt splices used for replacing sections of tubular members.

diameter are drilled in the stub ends of the original member and in each end of the new section for rosette welds as shown in the figure. The procedure for assembling and welding these joints is as follows:

1. Insert the sleeves in the ends of the new section.

2. Center the new section of tubing and with a scriber inserted in one of the holes move the sleeves into position.

3. Weld the joint between the tubes at one end and the rosette welds on each side of the tube joint.

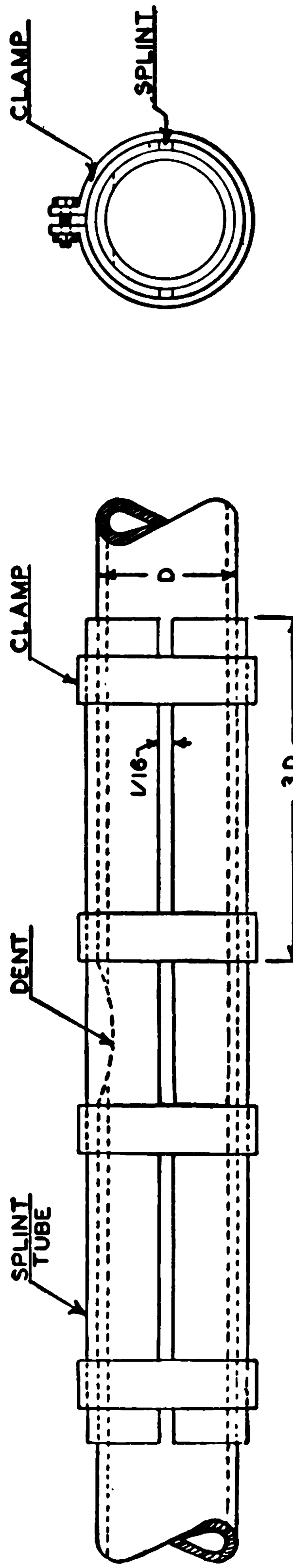


FIGURE 72.—Reinforcement of dent in heat-treated tubular member.

4. Permit the first joint to cool, then adjust the brace and clamp to provide for contraction and shrinkage of the weld. This allowance should be about $\frac{5}{64}$ inch.

5. Make the rosette welds on one side of the opposite tube joint, then tack weld the joint between the tubes.

6. Remove the brace and clamp and complete the joint.

80. Repair and reinforcement of damaged structural members.—Tubular members with minor dents may be repaired without removal as shown in figures 72, 73, and 74.

a. Heat-treated compression members with minor dents may be brought up to their original strength by means of a split tube clamped in place over the damaged portion as shown in figure 72. The split tube must be of an equal wall thickness to the tube being

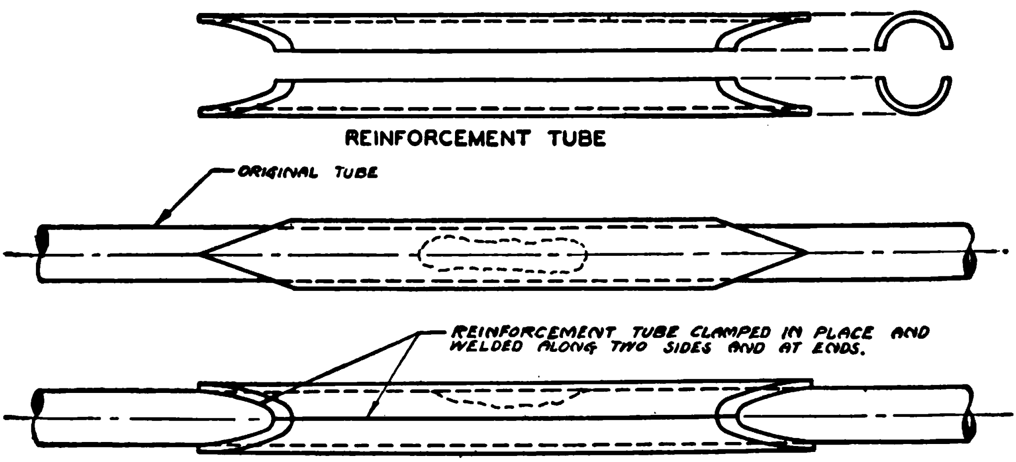
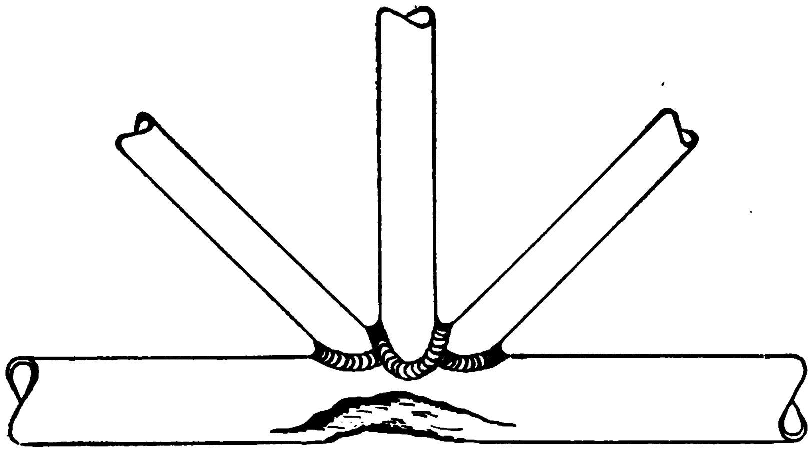


FIGURE 73.—Repair of tube dents by welding.

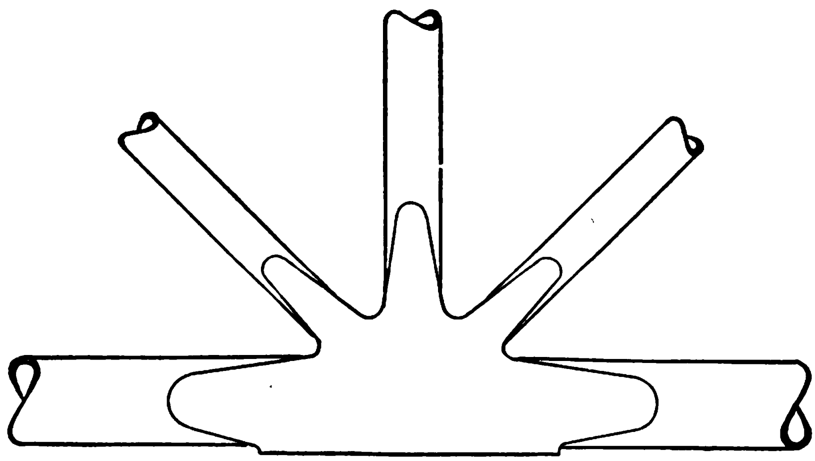
repaired, and must be clamped tight enough to prevent it or the clamps from loosening in service.

b. Dents in tubular members which are not heat-treated, should be reinforced as shown in figure 73. This method is satisfactory for short struts or dents in long members near the fixed end. It should not, however, be used for long struts where the injury is near the center of the span, as these members are under greater bending stress at this point and the full strength must be maintained.

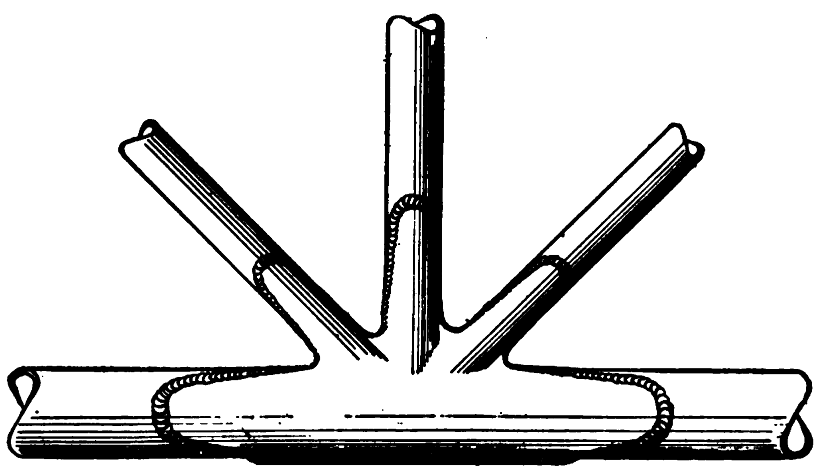
c. The main member of any tubular assembly, with an injury such as a dent at points where truss members terminate, may be repaired by welding a sheet metal patch over the damaged portion as shown in figure 74. The patch must be of the same thickness as the damaged tube and of a size sufficient to cover the injury. The fingers that extend onto the truss members should have a width equal to the diameter of the brace tube and a length equal to 3 or 4 diameters.



① Damaged section.



② Fitting of patch.



③ Finished repair.

FIGURE 74.—Repair of dents in main structural members at station points.

The ends of the fingers should be pointed or round to prevent heating the tube to an annealing temperature in a direct cross section at these points.

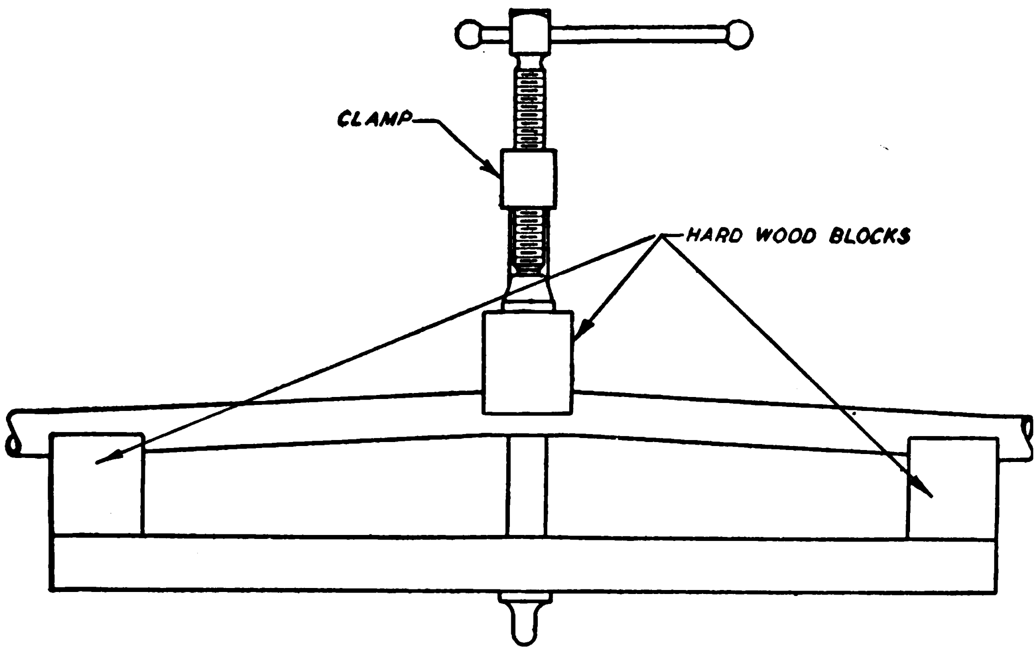


FIGURE 75.—Method of straightening bent tubular members.

d. Bent steel tube structural members may be straightened and used without further repair if they are not crushed, crinkled, or dented. Fixtures for straightening bent members are shown in figure 75 and consist of a bar, a heavy duty **C** clamp, and three blocks of

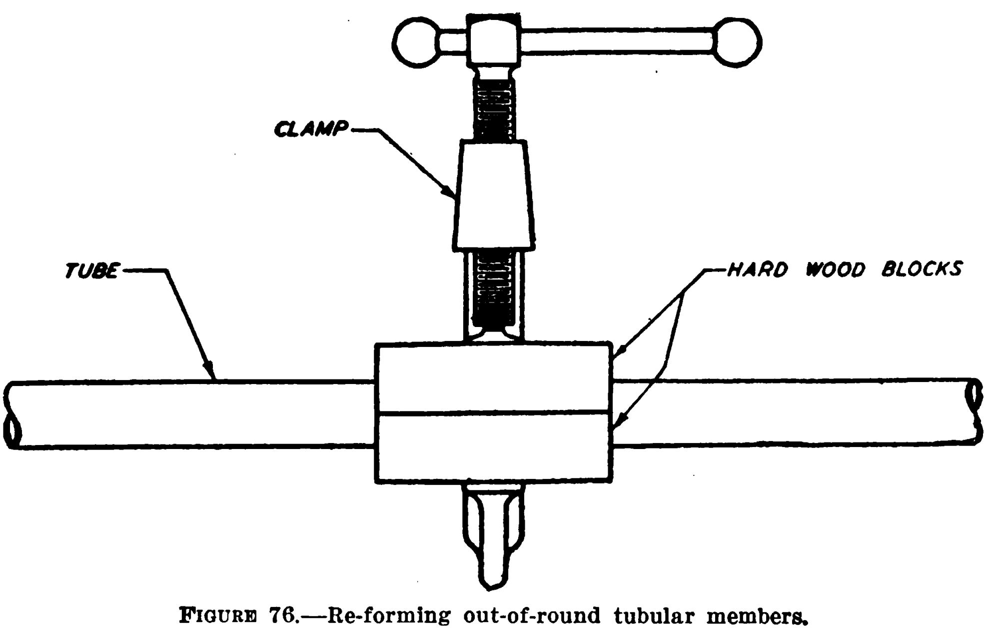


FIGURE 76.—Re-forming out-of-round tubular members.

hard wood grooved to fit the tube. These blocks are held in place with the clamp and bar, and the member pulled back into position by means of the clamp adjusting screw.

e. Tubular members that are slightly flattened may be re-formed as shown in figure 76 and used without further repair. The procedure is as follows:

(1) Secure a hard wood block about 4 inches square and bore a hole through the center equal in diameter to the tube to be re-formed.

(2) Cut the block through the center of the hole and apply a small amount of cup grease or oil to the grooves.

(3) Clamp the blocks in position over the out-of-round portion of the tube, and rotate the assembly while gradually tightening the clamp until the tube is well rounded.

81. **Attachment and repair of fittings.**—*a.* Aircraft fittings may either be built up of one or more thicknesses of sheet steel or forged and machined from bars or billets. The method of welding fittings to tubular members depends upon the load stress that they will be subjected to under operating conditions. (See fig. 77.)

b. Moderately stressed fittings which are not subject to vibrating stresses are generally made of a single thickness of steel sheet and are welded to one wall of the tube only as shown in figure 77①.

c. Fittings or lugs used to transmit high stresses are welded to the supporting member at more than one point. High stressed fittings attached to the main member of a structural unit midway between station points are welded to both walls of the tube as shown in figure 77②. In this case the tube is slotted and the fitting inserted.

d. Fittings attached to the main members of tubular structures, where brace members terminate, are also welded to the brace members in general practice. The main members and ends of the brace members may be slotted and the fitting welded in as shown in figure 77③, or the fitting may be built up of two or three sections with fingers extending to the brace members as shown in ④.

e. Figure 78 shows the more common methods used in attaching strut end fittings by means of welding.

(1) Figure 78① shows a typical male fitting for round struts. This fitting consists of a bearing sleeve or bushing welded to the strut end, which is reinforced with a steel plate, formed around the bearing. The plate is welded to the bearing sleeve and strut with a fillet weld.

(2) The fitting shown in figure 78② is a typical female strut end connection used for round struts. This fitting is forged and machined to fit into the strut end and is attached to the strut with a combination riveted and welded joint.

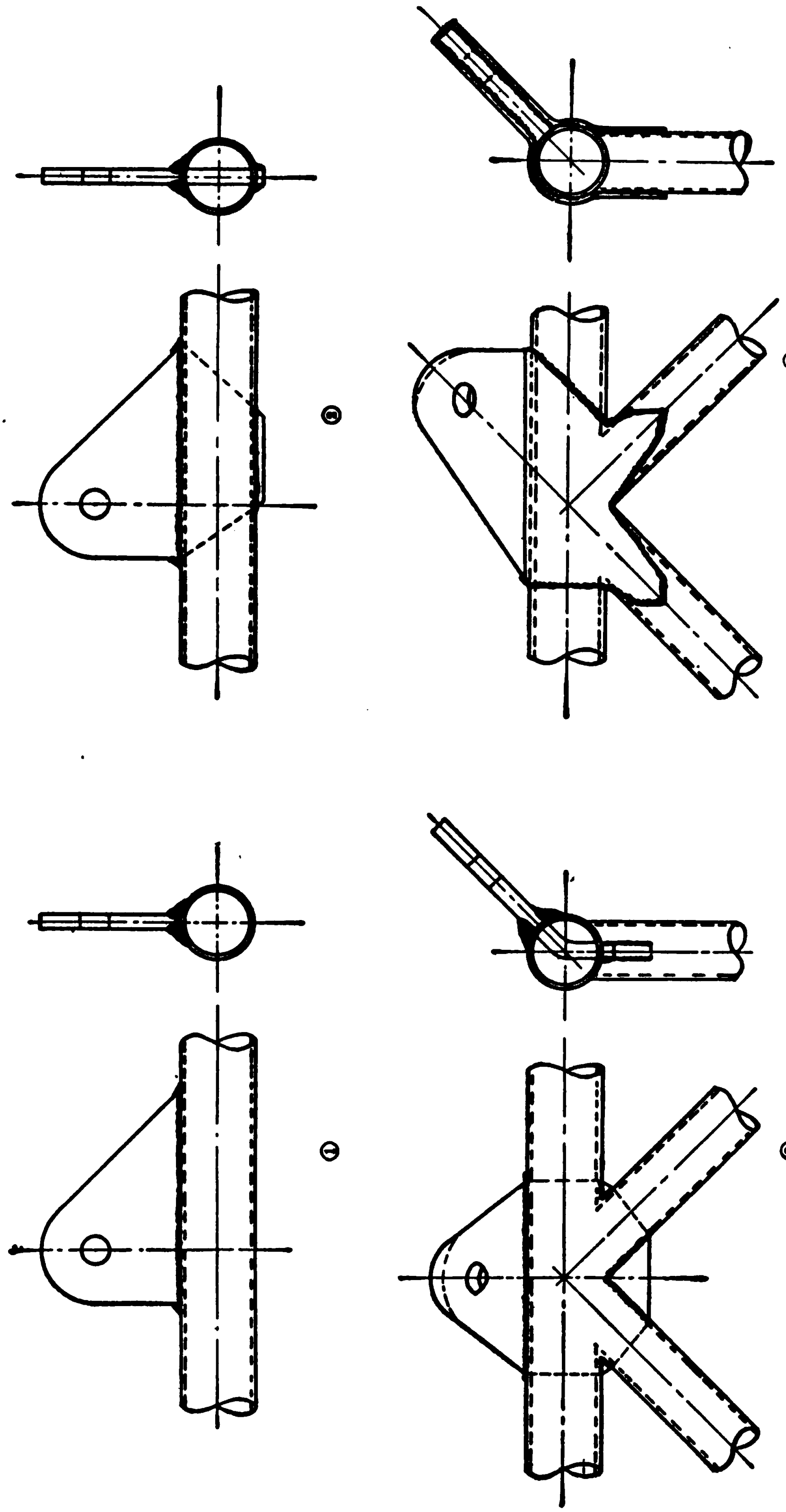


FIGURE 77.—Methods used in attaching fittings to tubular members.

(3) The connection shown in figure 78③ is an example of a forged and machined male fitting used for elliptical or streamline struts. This type of fitting is inserted by slotting the strut end to receive its tang, and attachment is made by means of a fillet weld.

(4) Figure 78④ shows a typical female fitting used for streamline or elliptical struts, although it may also be used for round sections.

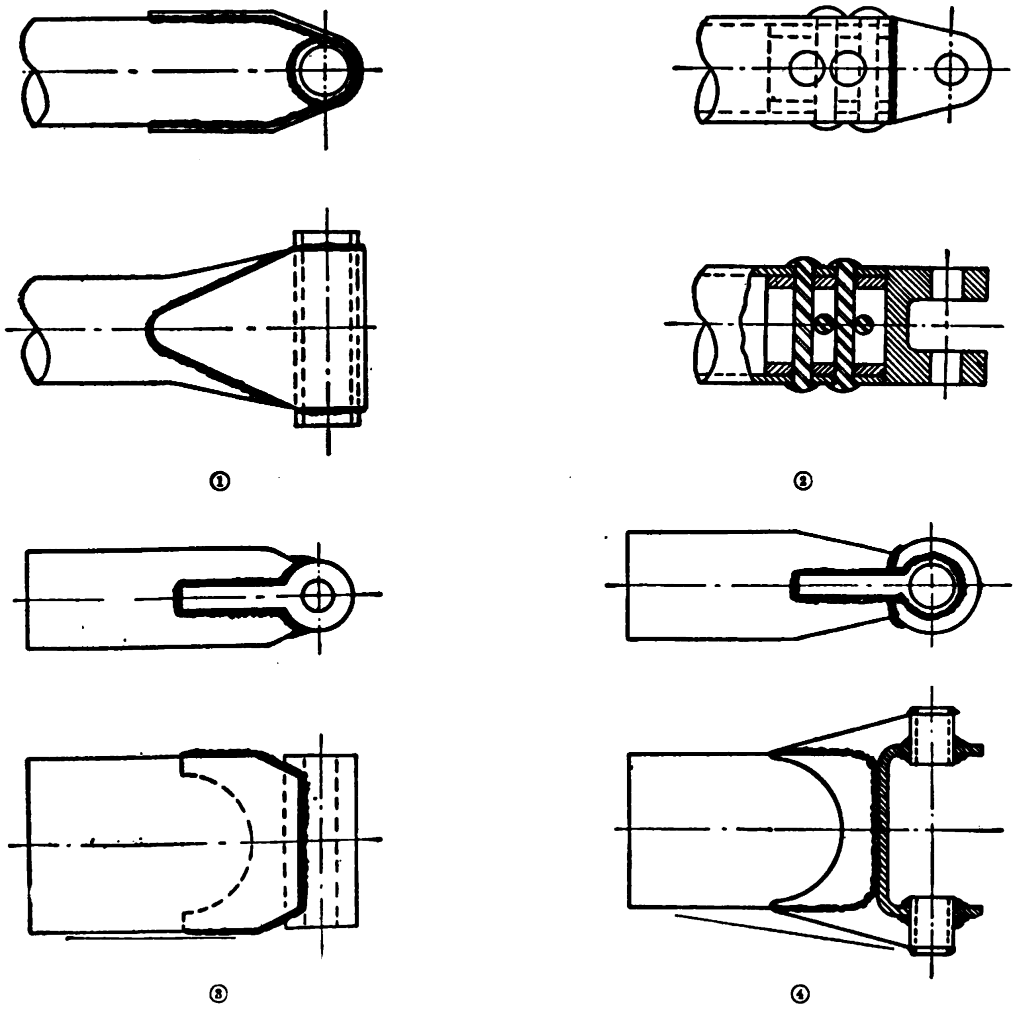


FIGURE 78.—Methods of attaching strut end fittings.

This connection is built up of sheet steel and bearing sleeves. The strut end is slotted and formed to receive the fitting.

f. Broken or worn fitting which is welded to structural members should be removed and a new fitting installed. The replacement fitting must have physical properties equal to or greater than the original unit. The damaged fitting must be removed without damage to the tube to which it is attached, and the new fitting installed in the same manner as the original. In case of a damaged fitting attached

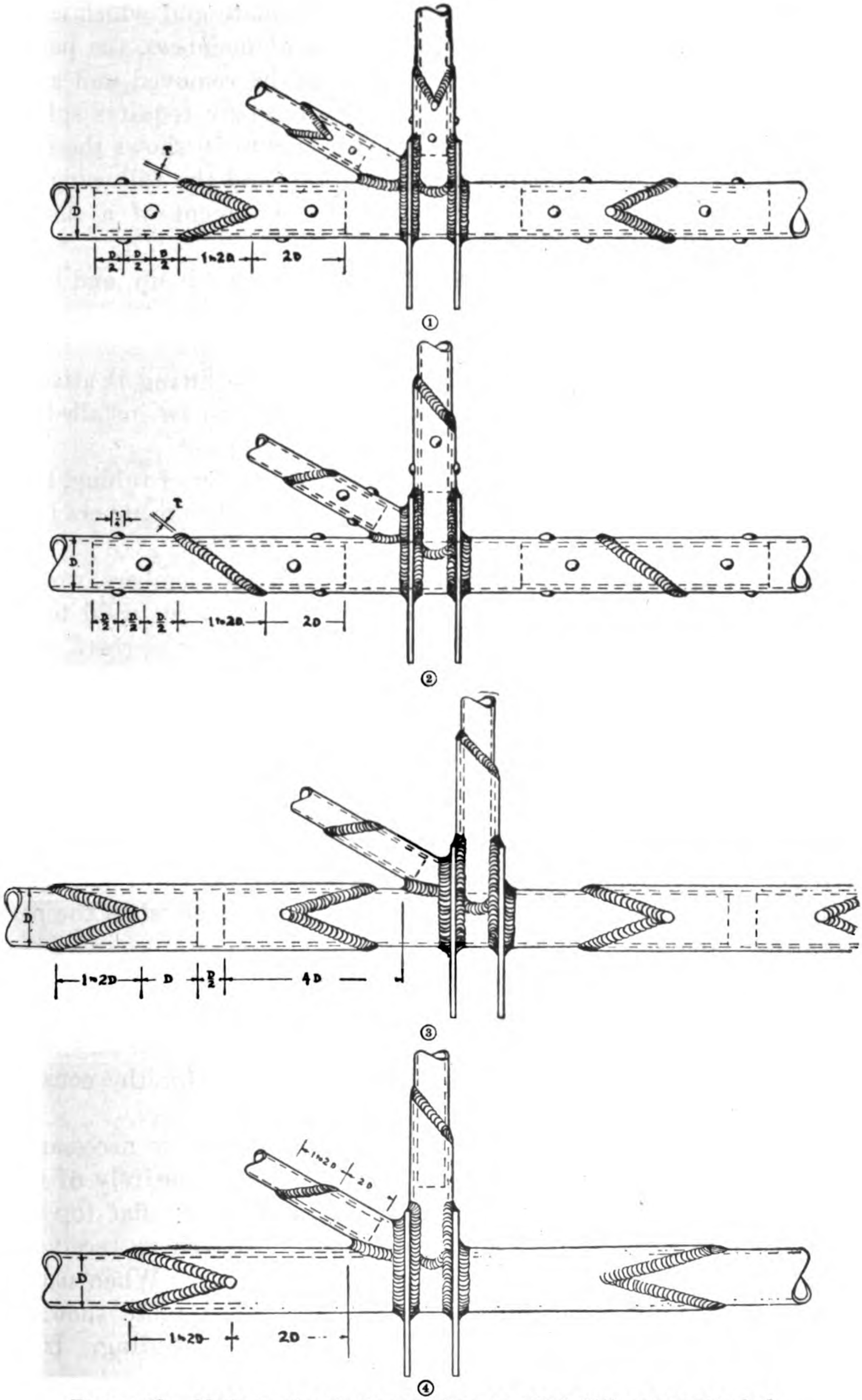


FIGURE 79.—Methods of replacing members to which fittings are attached.

to a main member where truss members terminate and which cannot be removed without damage to the structural members, the part of the tubing with the damaged fitting should be removed and a new section and fitting installed. This kind of repair requires splicing of the truss members and main member. Figure 79 shows the methods that may be used for this type of repair, and the following procedure is given as an example in the replacement of a fuselage fitting:

(1) Place the structure on suitable trestles, line it up, and clamp or block it in position in order to maintain alinement while making the repair.

(2) Remove the section of tubing to which the fitting is attached.

(3) Obtain a detailed drawing of the fitting to be installed and make a new one.

(4) Weld the fitting in position to the new section of tubing, locate the repair part in position, and line it up with other members in the station.

(5) Weld the several joints between the tubular members, working progressively from one to the other, and permit each weld to cool before welding the succeeding joint. Welding should start at the joints of the main member and proper allowance for shrinkage of each joint must be provided.

82. **Construction of steel tube assemblies.**—In the construction of steel tube assemblies by means of welding, it is essential that a suitable jig be provided. This is necessary to support and hold the various members of the assembly in their correct position until they are permanently fastened. These jigs should be rigid enough to withstand ordinary strains without losing their shape when the parts are being assembled.

a. Jigs for welding flat assemblies in production plants are generally made of boiler plate 3/8 to 1/2 inch thick. These plates are fitted with suitable blocks or clamps to receive the members of the assembly. Figure 80 shows a typical welding jig for the construction of flat assemblies.

b. In the construction of flat assemblies where it is necessary to build a single unit only, the jig may be constructed entirely of wood on the same plan as described for production jig. A flat top table may be used for the base, and wood blocks grooved to receive the members fastened to this base with screws or nails. When using a wooden jig, a piece of fairly heavy iron or steel plate should be placed under the joint to protect the wood during welding. Heavy sheet asbestos may also be used for this purpose.

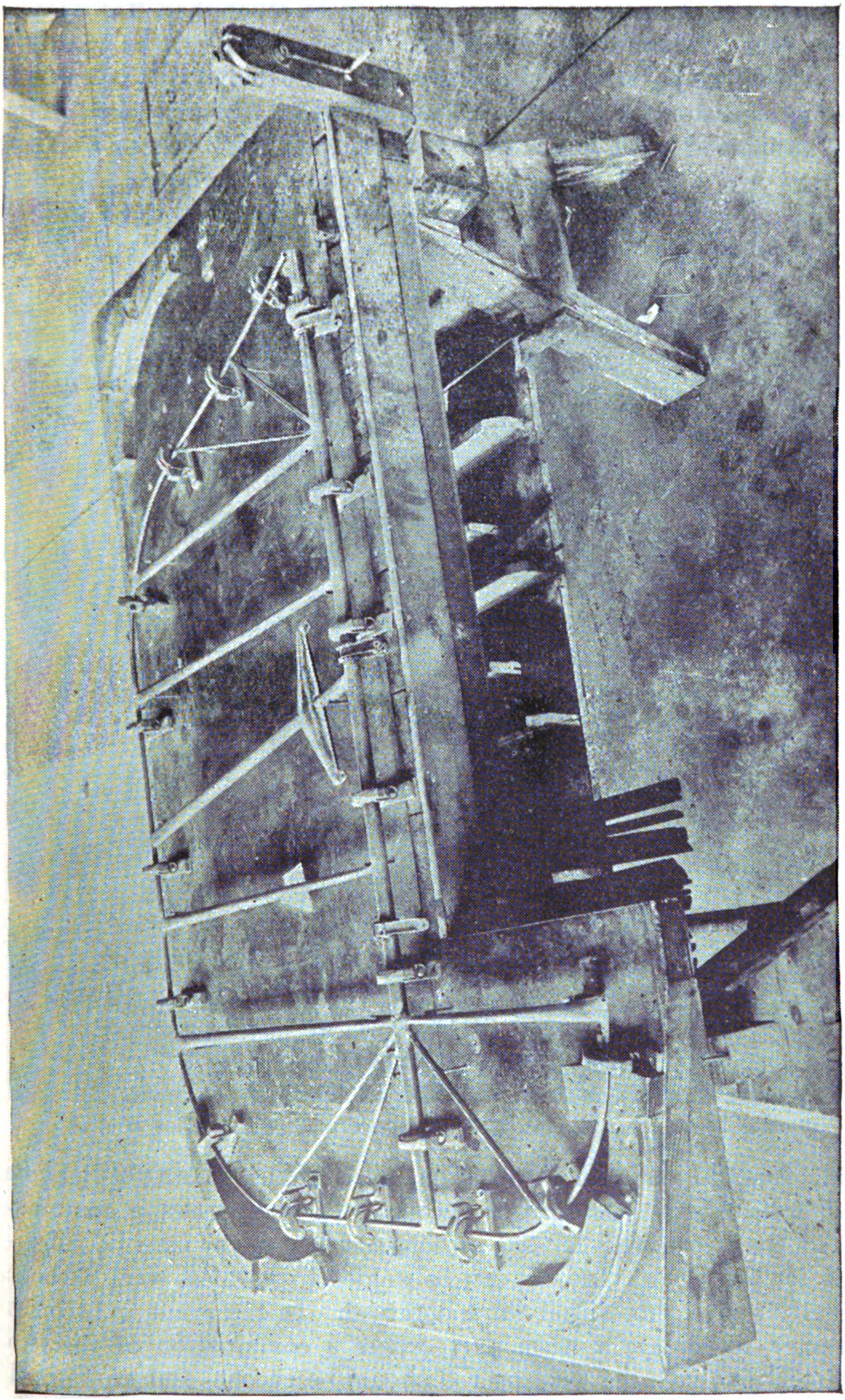


FIGURE 80.—Welding jig for constructing flat tubular assemblies.

c. In the construction of tubular structures other than flat assemblies, a more elaborate jig is generally required. Figure 81 shows a typical welding jig used in the construction of a radial engine mount. This jig consists of a heavy steel base plate and top plate of lighter gage, supported with angle iron vertical members. These vertical members are welded to both plates to obtain maximum rigidity. Clamps and holes are provided for holding the members to be welded and the assembly is left in the jig until cool.

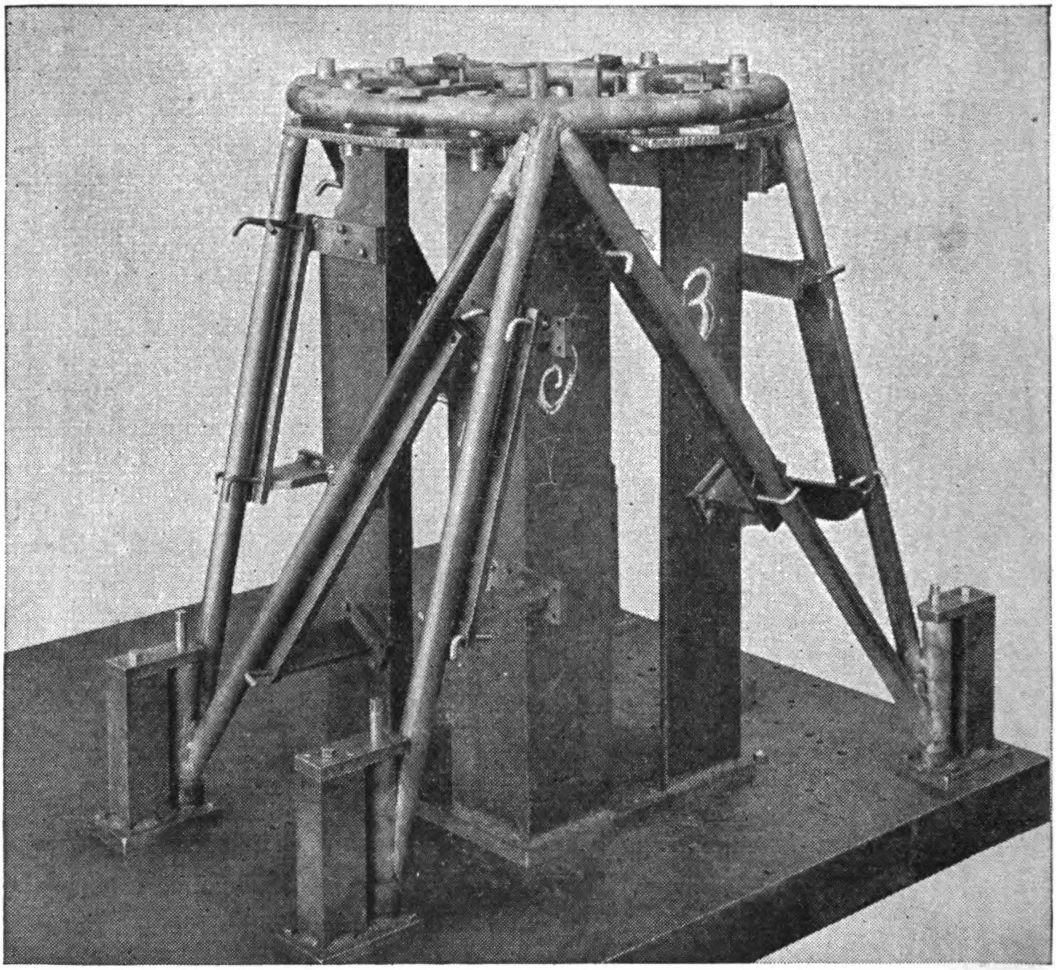


FIGURE 81.—Welding jig used in construction of a steel tube engine mount.

83. Engine exhaust manifolds.—*a.* Exhaust manifolds may be constructed of stainless steel or Inconel. In many cases, a combination of the two metals is used although either metal may be substituted for the other. Inconel can be welded to stainless steel without difficulty and a substantial joint obtained. In the event it becomes necessary to replace a worn part, where a combination of the two metals is involved, the welding rod should be Inconel and an Inconel welding flux used.

b. In the construction of exhaust manifolds, a substantial jig is required to hold the parts in position and maintain alinement during assembly. Figure 82 shows an assembly jig used in the construction of an in-line engine exhaust manifold. This unit consists of a heavy bed plate with fittings attached for locating and holding the parts

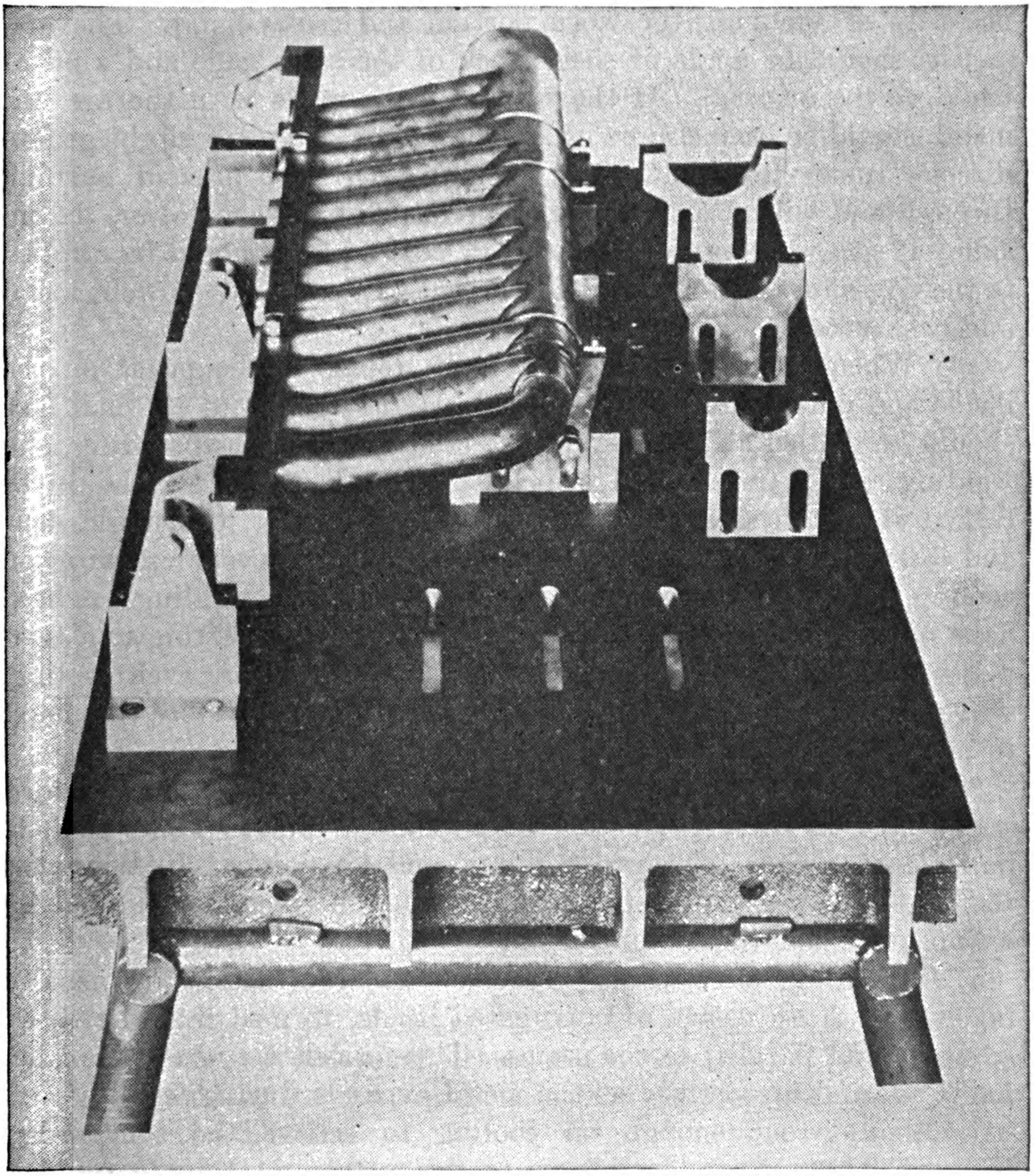


FIGURE 82.—Welding jig used in construction of engine exhaust manifold.

in position during welding. The design of this jig permits the parts to expand and contract in a longitudinal direction but keeps them alined with each other.

c. The repair of exhaust manifolds consists principally in replacing broken or worn fittings, patching worn parts, and welding cracks or breaks that occasionally develop.

(1) When replacing a damaged fitting, the old fitting, including the weld metal deposit, should be ground off and the section cleaned on the inside. The new fitting may then be made and welded in place.

(2) Sections of the exhaust manifold that are telescoped together are subject to wear and must be repaired at intervals. This repair necessitates removing the worn portion and replacing it. The new section should be made of sheet stock of the same gage and kind of metal as the original. If the weld is to be made with the arc, the metal should be backed up with a copper strip having a slight groove directly under the joint. The backing strip will prevent burning through and will also eliminate projections of weld metal on the inside. If gas welding is used, a heavy coat of flux should be applied to the edges on the under side to prevent oxidation of the weld metal and base metal.

(3) When a crack or break is to be repaired, the metal on the inside and outside must be clean and bright. A 1/16 to 3/32 inch hole should be drilled at each end of the crack to prevent spreading. In welding cracks that exceed 2 inches in length, the break should be tacked at 2 inch intervals. Preheating of the part to between 400° and 600° F. will minimize distortion and help prevent cracking on cooling from the welding heat. Where considerable welding has been done in the repair of stainless steel exhaust units, reheating to a temperature of between 1,900° and 2,000° F., followed by even cooling, will relieve residual stresses caused by welding and restore the metal to its original condition.

84. Fuel and oil tanks.—*a.* There are several types of welded seams used in the construction of aluminum tanks. These include butt joints, corner joints, edge joints, and lap joints. In the event that baffle plates are riveted to the shell, the rivets are headed by welding to make them liquid tight.

b. In welding tank seams, expansion and contraction are usually taken care of by means of corrugated beads, formed into the sheet, adjacent and parallel to the seams. These beads serve as expansion joints, closing up slightly as the metal expands during welding and straightening out enough on cooling to relieve the contraction strains. They also add stiffness to the metal and help to prevent buckling of the shell. Figure 83 shows the types of joints commonly used in the construction of tanks. The location of the expansion beads is also shown in this figure.

(1) Joint (fig. 83①) shows a riveted joint between the shell and baffle plate with the rivet headed to the shell by welding.

(2) Joint (fig. 83②) shows another method which is sometimes used to secure the baffle plates to the shell. In this case, the plates either extend through a slot and are welded to the shell or are located at seams in the shell and welded to the shell at the same time these seams are made.

(3) Joint (fig. 83③) shows a mechanical lock seam sealed by welding. This joint is sometimes used in the construction of the shell.

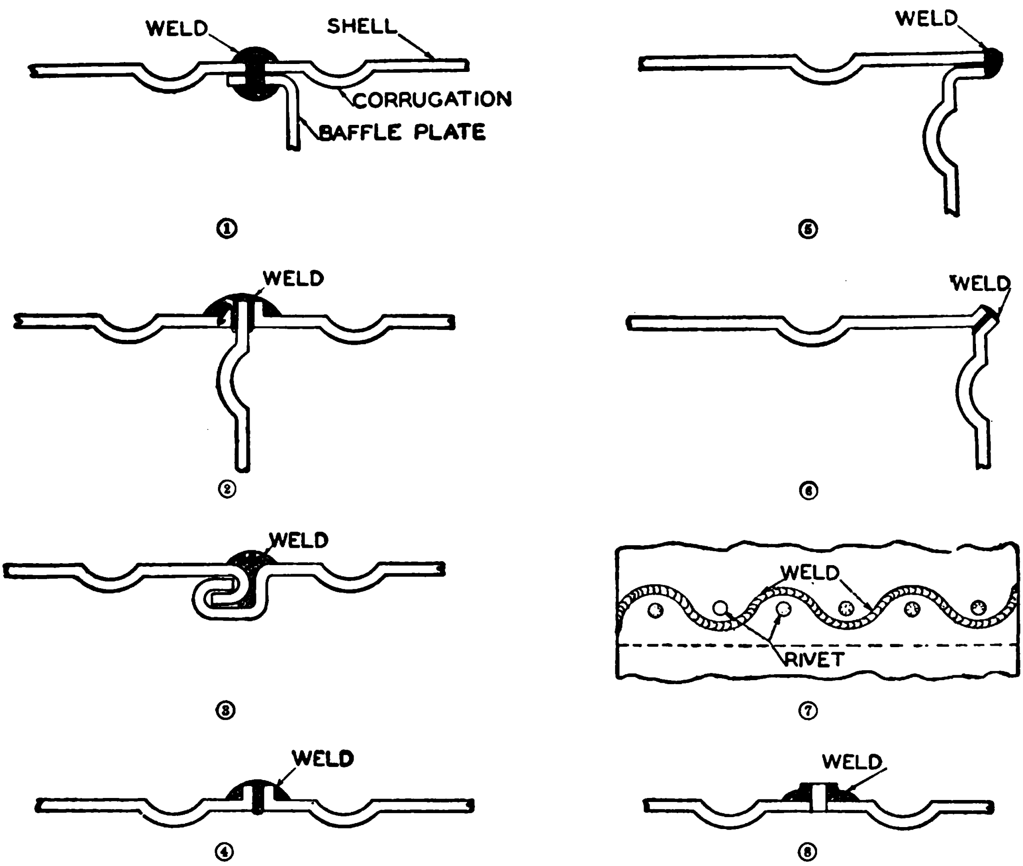


FIGURE 83.—Seams used in construction of fuel and oil tanks.

(4) Joint (fig. 83④) is generally used for small seams. The turned edges add stiffness to the sheet at the joint and help to maintain its alinement during welding, as well as furnish the additional metal required in the weld.

(5) Edge joints (fig. 83⑤) is sometimes used for corner seams in tank construction and for welding the hand hole cover plates into the shell.

(6) Joint (fig. 83⑥) is another type of corner seam used in tank construction and is welded in the same manner as the flanged butt joint.

(7) Scallop joint (fig. 83⑦) is used for the shell seams of tanks. The sheets are lapped and riveted together at the points shown in the figure. The edge of the upper sheet is then welded to the surface of the under sheet and the rivets sealed by welding.

(8) Joint (fig. 83⑧) is of the butt type with the inclusion of a stiffener strip between the butt ends. The strip is extended above the plates, and fillet welds are used to secure the entire assembly.

c. Welding in the repair of fuel and oil tanks is confined to those which have been originally fabricated by welding. Before attempting to repair a fuel or oil tank with an open flame, the tank must be drained and thoroughly cleaned to remove explosive gas vapors. The procedure for cleaning is as follows:

(1) Flush the tank for 15 minutes with hot water. The water must be admitted at the bottom and allowed to overflow at the top to remove deposits of oil or fuel adhering to the baffle plates and sides of the tank.

(2) After flushing with water, clean the tank with live steam for a minimum period of 3 hours for fuel tanks and 1 hour for oil tanks. The tank should be mounted so that the steam may be fed in at the top and allowed to escape through an opening at its lowest point. During this process all other openings should be closed.

(3) If facilities are not available for steam cleaning, the flushing with hot water must be continued for a minimum period of 1 hour, following which the interior of the tank must be thoroughly dried with compressed air. This method is not as positive as steam cleaning and therefore should not be used unless absolutely necessary.

(4) When the exterior of the tank is to be cleaned with paint remover or any other combustible solvent, this cleaning should be done prior to the flushing or steaming of the tank.

(5) The repair work must be accomplished as soon as possible after the tank has been cleaned and dried. A tank that has been flushed or steam cleaned must not be allowed to stand for more than 30 minutes before being repaired. Should this become necessary for any reason, the cleaning process must be repeated before applying any heat.

d. Repairs to tanks by welding consist, in general, of rewelding seams which have opened up, welding a crack or break in the shell, replacing broken or sheared baffle plate rivets, replacing worn or otherwise damaged fittings, etc.

(1) Welding of opened seams requires the removal of all excess metal deposited in the original weld. A $\frac{1}{16}$ to $\frac{3}{32}$ inch hole, drilled at each end of the fracture, will prevent it from spreading. In re-

welding the seam, full penetration must be obtained to prevent a recurrence of the failure. If the seam is more than 2 inches long it should be tack welded at intervals of 1 to 2 inches to hold the edges in alinement.

(2) A crack or break in unwelded portions of the shell will require the same procedure as outlined for rewelding seams.

(3) Broken baffle plate rivets may usually be repaired by placing a new rivet between the original rivets that have failed. In some instances, the original rivet may be drilled out and a new rivet installed in its place. In the latter case, the next larger diameter rivet is generally used to obtain a tight fit. A repair of this type requires an opening to be made in the shell near the rivets to be replaced. The opening must be large enough to insert the hand and should be round or have rounded corners. After the rivets are replaced and welded, the opening must be closed with a new plate of the same gage as the shell. No. 2S aluminum sheet may be used for this plate where the tanks are constructed of the 3S or 52S aluminum alloy.

(4) Worn or broken fittings that require replacement should be cast of aluminum-silicon alloy. An alloy of 50 percent scrap aluminum alloy propeller metal and 50 percent 2S aluminum is considered a suitable substitute.

(5) Broken baffle plates must be welded or replaced, depending upon their condition. If the repair can be made by welding the break, an opening must be made in the shell, near the damaged baffle, as previously described. The baffle may then be welded and the opening in the shell sealed. If the baffle must be replaced with a new one, the portion of the shell to which the damaged baffle is attached should be removed with the baffle and an opening made in the shell for access to the rivets holding the sections together. When removing rivets, care must be taken to prevent injury to the parts to which the damaged baffle is attached. This may best be done with a very thin chisel and punch. After the damaged baffle is removed, a new one must be riveted to a new shell section, then tacked in place, welded, and the repair completed by closing the hand hole opening.

(6) After repairing a tank, it should be tested for leaks, using 2 or 3 pounds of air pressure and applying soap suds to all seams, rivets, etc. Immediately after testing, the welding flux must be completely removed.

(7) The welding of fuel and oil tanks should never be done near inflammable materials or in a building containing such materials.

85. Cowlings.—*a.* The principal repairs to aluminum and aluminum alloy cowling consist of patching worn spots, welding cracks or breaks caused by vibration, and replacing broken or worn fittings.

(1) Cracks or breaks in cowling are repaired by welding the fracture. Cracks running into the sheet from the edge or from a hole in the cowl should be lined up, tacked, and then welded, progressing from the end of the crack toward the edge or opening. The weld should be made with sufficient penetration to give a small bead on the under side.

(2) Worn spots in cowling may be repaired by removing the worn section and replacing it with a new piece. The new piece should first be cut to fit the portion removed and formed to the required shape. It may then be located in position and tack welded at intervals of 1 to 2 inches around the edges, followed by the finish weld. The penetration should be sufficient to give a small bead on the under side.

b. Cowlings which have been repaired by welding should be finished on the outside to a smooth surface. Any wrinkling or buckling caused by the weld must be hammered or rolled out.

86. Aircraft plumbing.—*a.* Repairs to copper and brass fuel, oil, or coolant lines consist of replacing damaged fittings and annealing the lines when the equipment on which they are installed is being overhauled. Each time a line is removed for repair, it should be annealed to remove the effects of working. Copper and brass lines are annealed by heating to a temperature of 1,000° F. After heating, copper lines are quenched in cold water to loosen the scale caused by heating and to increase the ductility of the material. Brass lines and fitting must be allowed to cool at room temperature, and under no circumstances should they be quenched as a sudden reduction in the temperature of heated brass will, as a rule, cause it to crack. Heating of the lines to anneal them may be accomplished by means of any blowpipe flame that will furnish sufficient heat. When annealing with the oxyacetylene torch, a large flame should be used and the tip of the outer envelope allowed to supply the heat. Extreme care must be exercised to avoid overheating the line at any point.

b. When it is necessary to replace a damaged line fitting or coupling, the part may easily be removed by heating to a temperature that will loosen the solder. After removing the fitting, the end of the tube must be thoroughly cleaned and a new fitting soldered in its place using silver solder.

c. New copper and brass lines must always be fabricated from tubing in the annealed condition. The line should first be cut to the

required length and the fittings soldered on. All close bends should be annealed after the line is formed, as copper work hardens readily at such points.

d. After annealing or repairing copper and brass lines, all scale and flux caused by heating must be removed before the line is installed.

87. Rewelding failures in welded steel joints.—*a.* This kind of repair necessitates the removal of the previous weld metal deposit in order to obtain the proper depth of fusion during the repair. The removal of the original weld metal is best accomplished by means of a thin cold chisel and hammer. Weld metal may also be removed by grinding when the weld is accessible. Any protective coating or scale in or near the weld should also be removed.

b. The joint may be rewelded with the electric arc or oxyacetylene flame. The arc is preferable for parts which are in the heat-treated condition as the heat is more localized and the heat strains will be less than those caused by gas welding. If the metal is less than 0.0625 inch in thickness and cannot be backed up, the gas flame will give the best results in most cases.

c. Weld failures in heat-treated alloy steel parts should be normalized before welding so as to prevent additional cracks from heat strain. After welding, the part should again be normalized to relieve the heat strains, then reheat-treated. If the work cannot be reheat-treated after welding, the joint should be preheated to between 600° and 700° F. before welding. Welding of such parts without being subsequently reheat-treated should not be attempted without special authority.

88. Control of distortion due to welding.—In the construction of steel tube structural units and steel fittings, provision must be made for expansion, contraction, and shrinkage of the weld metal, if dimensions are to be maintained and cracks in the weld and base metal are to be prevented. It is also important to prevent any great loss of metal thickness from excess scaling during the welding process. These factors may be controlled within reasonable limits by the proper welding procedure.

a. Shrinkage.—The method usually employed to provide for the shrinkage of welds in the construction of steel tube structural units is to make the required allowance for normal shrinkage as predetermined by a trial weld under similar conditions. In most cases, an allowance of $\frac{1}{32}$ inch at each end of a web member of a truss will be ample. This same rule will apply in the construction of fittings built up of sheet metal.

b. Cracking.—This condition can be prevented by minimizing strains on the weld and hot base metal due to weight or restriction of normal expansion and contraction.

(1) In the construction of steel tube assemblies, it is good practice completely to weld one end of the web member to the flange member of a truss and allow it to cool before welding the opposite end. Joints of an assembly in which several members terminate should be welded first and allowed to cool before any welding at the opposite ends is attempted. This is due to the fact that the extra time required to weld such joints will allow the heat to travel away from the weld into the members and produce greater expansion in them. In case the members are connected to similar joints at the opposite end, it is advisable to apply heavy clamps, chill plates, or wet asbestos to the members, near the weld, to prevent this heat travel, in order to hold the expansion to a minimum.

(2) In the construction and attachment of fittings, shrinkage strains can be reduced considerably by starting the weld at the fixed end and welding toward the free end of the seam or opening. Cold rolled alloy steel shapes or heat-treated forms should be annealed before welding to reduce the brittleness of the metal. It is also good practice to relieve the stresses of alloy steel parts after welding by heating the entire part uniformly to a temperature of between 1,150° and 1,200° F., then allowing it to cool slowly. When making a combination riveted and welded joint, the rivet holes should be lined up and all welding completed before the rivets are driven. If this procedure is not followed, the expansion and subsequent contraction will develop a shearing stress on the rivets and elongate the holes.

c. Warpage.—This condition can be controlled in the construction of tubular assemblies by the use of sufficient clamps and properly constructed jigs. Progressive welding through the structure will also aid in maintaining alinement, and the heating of the member on the opposite side from which the weld is made will greatly reduce the strains.

SECTION XIV

WELDING TESTS

89. General.—Several methods of testing may be used to ascertain common welding defects. Tests of this nature are very necessary in

the selection of aircraft welders and may also be used as a check on the student's progress.

90. Types of tests.—The various tests commonly used for the determination of welding faults may be outlined as follows:

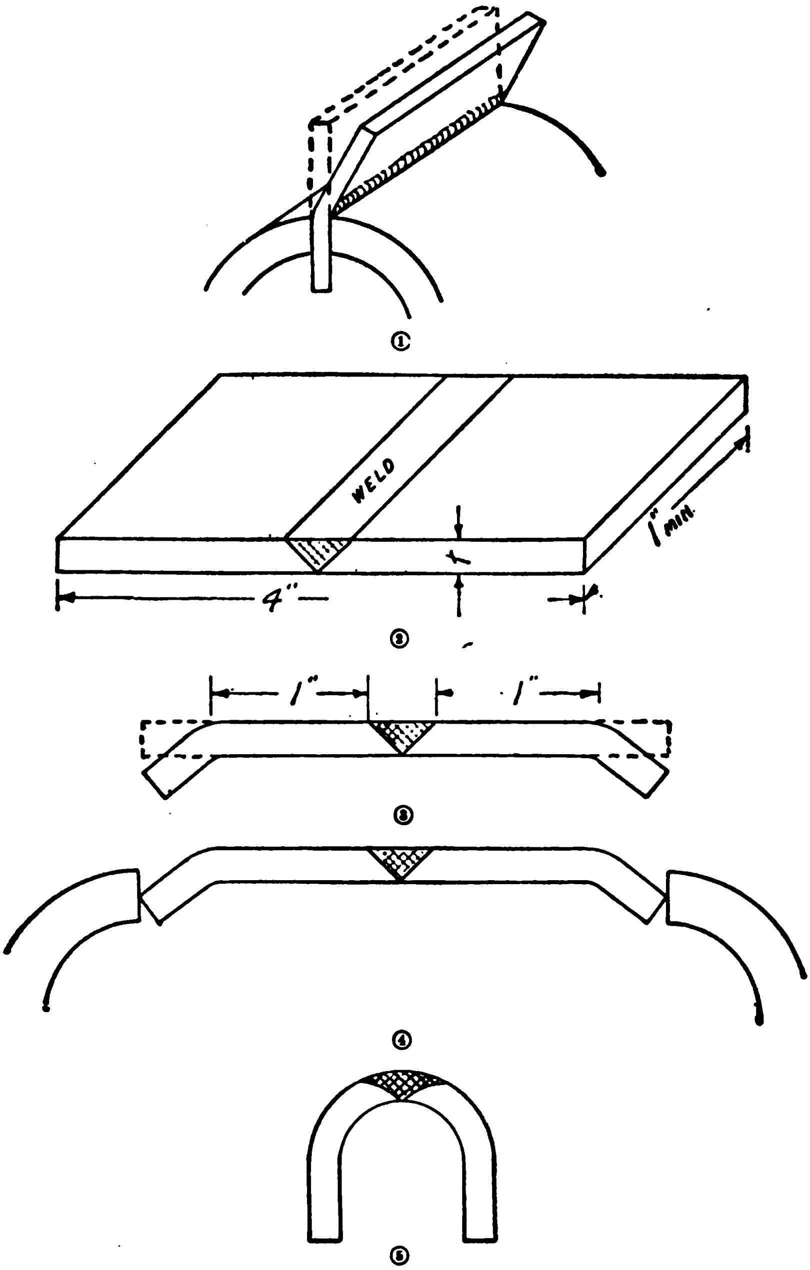


FIGURE 84.—Method of testing butt joints for weld defects.

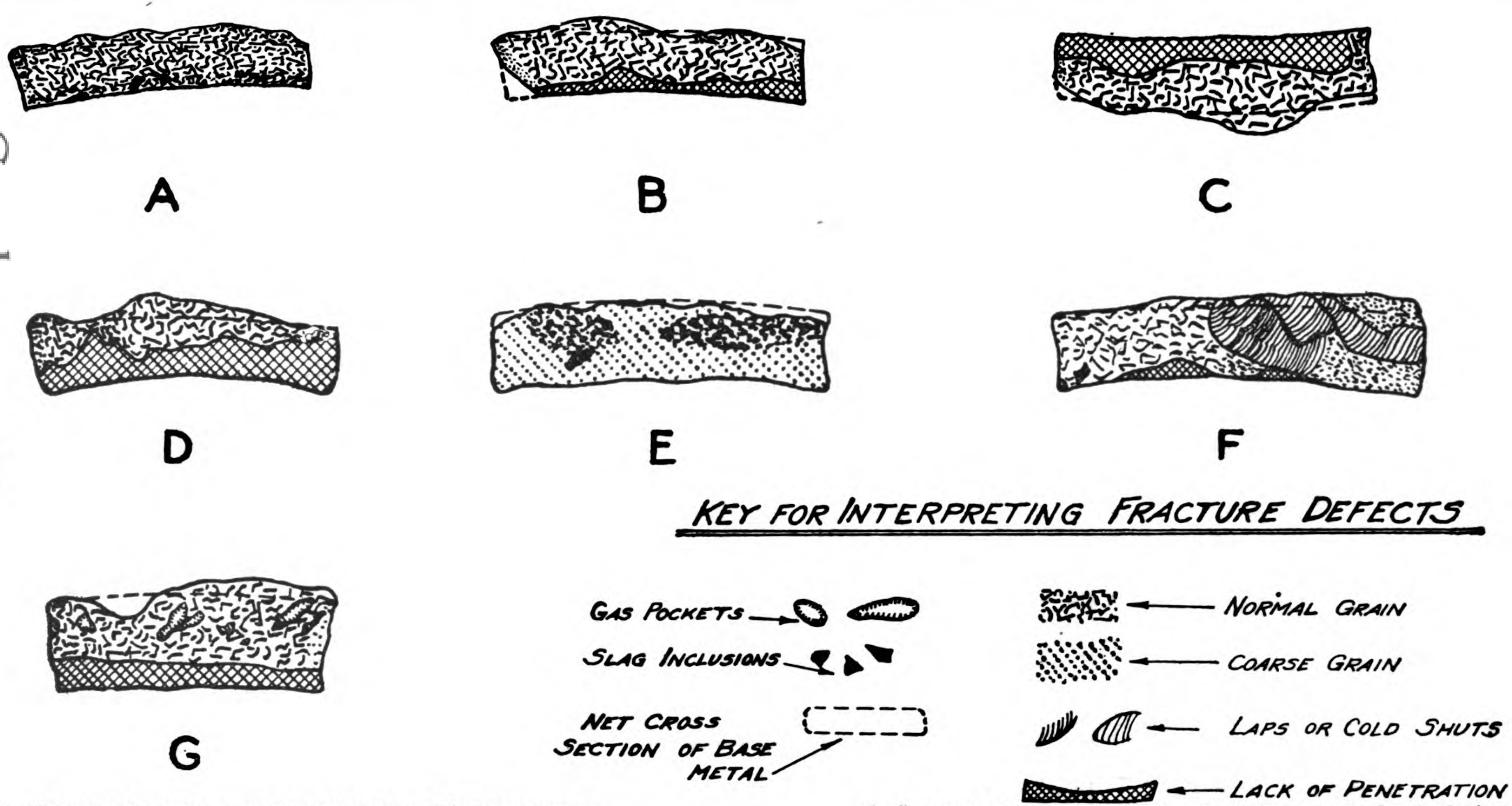
a. Bend test.—The bend test may be used to produce a fracture through the weld so that a cross section of the weld metal is exposed for examination. The ductility of the weld may also be determined in this manner.

(1) Figure 84 shows the procedure of making the bend test. The specimen is placed in a vise as shown in figure 84① so the jaws will grip the base metal just below the weld, then, with a heavy hammer, the projecting portion of the specimen is bent back toward the weld side until a fracture is produced. Metal less than 0.125 inch in cross section should be bent a full 180°. If the specimen fails to break on this bend, it is evidence of good workmanship and no further check is required. If a fracture through the weld is obtained, a careful examination must be made for weld faults, such as poor fusion of the weld metal with the base metal, failure to fuse the base metal to the required depth, gas pockets, slag inclusion, laps or cold shuts, and irregularity of grain structure. Figure 85 graphically illustrates these common defects.

(2) The ductility of the weld metal and the fusion of the weld metal with the base metal can be determined by bending coupons cut from weld specimens. This test should be used for metal 0.125 inch in cross section and heavier. The reinforcement must be machined or ground off flush with the surface of the base metal as shown in figure 84②. The coupon is bent as in ③ and placed in a heavy vise. The vise jaws are then closed slowly, bending the coupon as in ④ and ⑤. When checking for elongation, the load must be stopped at the first sign of a crack or check in the weld, while if the test is also being made to determine proper fusion at the toe of the weld metal, the load should continue until a fracture is produced or the coupon is bent a full 180°. Coupons that bend 180° without cracking or checking can be considered as satisfactory.

b. Nick-break test.—The nick test is used principally for metals of heavy cross section in order to investigate the grain structure and determine the presence of slag inclusions, gas pockets, or cold shuts. Figure 86 shows the preparation of specimens for the nick-break test. Coupons are cut from a cross section of the specimen weld and nicked with a hacksaw on each edge at the center of the weld as shown in the figure. The depth of the nicks should be approximately 15 percent of the metal thickness with a maximum of ¼ inch. The coupon is supported on knife edges as illustrated and broken by a sudden blow applied at the weld. The blow should preferably be applied by a power hammer or falling weight and must be of sufficient intensity to cause a sharp, sudden fracture through the nicked portion of the coupon.

c. Etching test.—Some joints used in aircraft construction, such as the fillet welds between tubes and sheets, cannot easily be broken down to obtain an opinion of the welder's ability. These joints may be investigated, however, by etching, and such defects as illustrated



A. Normal weld, uniform grain structure, and full penetration.
B. Lack of penetration or fusion of base metal to under side of joint.
C. Lack of reinforcement, too much heat, and weld metal protruding on under side.
D. Lack of penetration and uneven reinforcement.
E. Coarse grain structure, lack of reinforcement, slag inclusion, and poor fusion to side wall of base metal.
F. Uneven penetration, slag inclusion, and laps or cold shuts.
G. Lack of penetration, uneven reinforcement, and gas pockets.

FIGURE 85.—Weld metal defects.

in the weld fracture test disclosed. When making an investigation of the quality of a weld by etching, the specimen should be a cross section of the weld at two or more points along the seam. The weld exposed at each cut must then be polished and etched with a solution consisting of equal parts of hydrochloric acid and water, or 1 part of nitric acid and 2 parts of water. The nitric acid solution is the faster of the two and attacks the metal immediately upon being applied. This fluid need only be left on the metal for 15 minutes while the hydrochloric acid solution will require

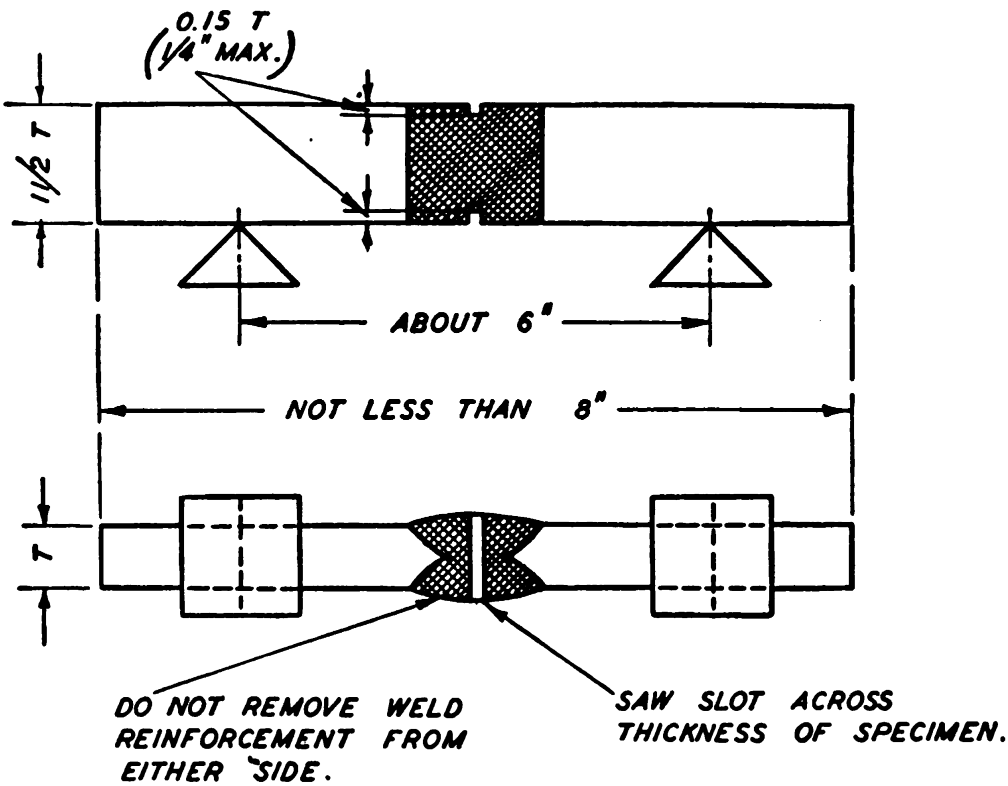


FIGURE 86.—Nick-break test for inspection of weld metal.

an hour or more. The procedure using either solution may be outlined as follows:

(1) Remove all saw marks from the surface with a fine mill file.

(2) Work out the file marks with fairly coarse grained emery cloth.

(3) Bring the surfaces to a mirrorlike finish by the use of successively finer grained emery cloth.

(4) Avoid touching the polished surfaces with the hands or any substance that may leave a film of grease or oil.

(5) Apply the acid solution with a brush or swab and allow the piece to stand until all action has ceased.

(6) Wash the surfaces with water followed by alcohol and allow them to dry.

(7) Examine the surfaces for defects, using a strong magnifying glass or microscope. The depth of fusion, uniformity of grain structure, etc., may be readily seen.

d. Tensile test.—The tensile test is used to determine the actual breaking strength of the weld. The yield point and elongation of the metal may also be determined in this manner.

(1) In the tensile test, a coupon is cut from the weld to be tested and put under tension in a suitable tensile testing machine. The ultimate strength is recorded and compared with the results obtained by testing the original metal under the same conditions.

(2) In the event that the sample breaks in the weld, one or more of the weld faults shown in figure 85 will be found on close examination. In the majority of tensile tests, where the reinforcement is machined off and the cross section of the weld is the same as that of the base metal, failure will occur in or at the edge of the weld. This is due to the enlargement of the grain structure by the welding heat. On examination, if the grain structure is exceptionally large and not uniform, or if other defects are found, such as previously described, the weld should be rejected as unsatisfactory.

(3) The strength of the weld for different metals depends to some extent upon the filler rod used. This is particularly true for welds in the high carbon and chrome-molybdenum alloy steels. Welds in 2S and 3S aluminum should be equal in strength to the base metal in the annealed condition if the sample has not been worked cold. Stainless steel and Inconel welds, properly made, should also be equivalent in strength to the base metal in the annealed condition without cold working.

91. Aircraft welder's qualification test.—A specific examination is required to qualify all welders for work on aircraft structures accepted for use in the Army Air Forces.

a. Materials and workmanship.—The materials used as samples for the qualification test must conform in chemical composition and physical properties with the materials used in the manufacturer's plant, for the fabrication of aircraft structures or fittings. In case both plain carbon and alloy steels are used, the samples must be made from alloy steel. Welding rod should also be of the type regularly used in production work.

b. Requirements.—A certificate must be filed with the procuring agency to show that the welder has passed the specified qualification test or its equivalent. This certificate must be accomplished by each

welder and bear the signature of both the welder and his supervisor.

CERTIFICATE FOR WELDER

Date ....

Employer .... Location of plant ....

Welder .... Age ....

Contract No. ....

Welder's experience (state time in years)

	D. C. arc	A. C. arc	Oxyacetylene or oxyhydrogen	Remarks
Training school				
Plant production				
Aircraft production				
Present employer				

Qualification test

Electric welding apparatus, Mfgr .... Model No. ....

Welding torch, Mfgr .... Model No. ....

Joint No	I	II	III	IV
Oxygen pressure				
Acetylene pressure				
Tip, size				
Amperes				
Volts				
Cycles				

Welding wire, Mfgr .... Size .... Coating ....

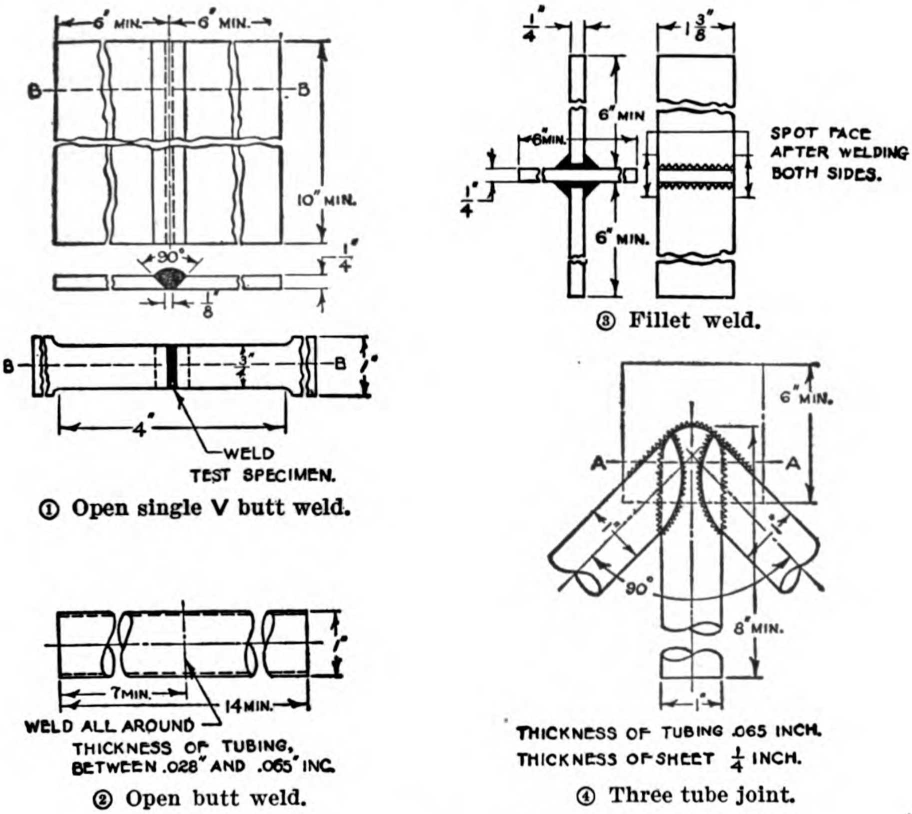
Trade name or analysis ....

Tubing, Mfgr .... Tensile strength ....

Chemical analysis ....

c. Qualification test.—The qualification test must consist of the manufacture of four types of joints. These joints are illustrated in figure 87 and are described as follows:

(1) *Open single* V *butt weld* (fig. 87①).—This weld must be made with a single reinforcement which, after welding, should be machined



① Open single V butt weld.

② Open butt weld.

③ Fillet weld.

④ Three tube joint.

FIGURE 87.—Qualification test for aircraft welders.

off and the sample cut up into test specimens of the form and dimensions shown. At least three samples must be cut and a tensile test made on each specimen. The average strength for the three samples must not be less than the values given in table XIII, and the strength of any individual specimen must not be less than 90 percent of this average value.

TABLE XIII.—*Tensile strength of weld metal*

Carbon content of filler rod (percent)	Carbon steel base metal (pounds per square inch)	Alloy steel base metal (pounds per square inch)
Up to 0.06, incl	45, 000	55, 000
0.07 to 0.12	50, 000	65, 000
Over 0.12	[1] 55, 000	[1] 70, 000

[1] These values will be used for alloy steel filler rod.

(2) *Tubular butt weld* (fig. 87②).—Specimens made for this test must be of the open butt type, with the tubes in both a horizontal and a vertical position. One set, consisting of a horizontal and a vertical specimen, must be welded on the bench while a similar set must be welded in an overhead position not lower than the welder's eyes. The overhead specimens must not be rotated. All joints should be tested as tensile specimens without removal of the reinforcement. The strength of the joints must not be less than 50,000 pounds per square inch for plain carbon steel and 80,000 pounds per square inch for alloy steel. These figures are calculated on the area of the base metal.

(3) *Vertical fillet weld* (fig. 87③).—This joint must be made with the sheet standing on edge and the pieces supported so that there is a clearance between the lower end of the seam and the jig. Two specimens are required and the joints must be tested in tension. Each sample should develop not less than 10,000 pounds per linear inch for plain carbon steel or 15,000 pounds per linear inch for alloy steel. The broken specimens should also be examined to determine whether or not the weld has been fused into the base metal in the corners.

(4) *Combination sheet and tube fillet weld* (fig. 87④).—This joint must be cut at section *AA* and each half polished and etched with a 50 percent aqueous hydrochloric acid solution at a temperature of approximately 180° F. A visual examination of the section must be made in order to determine the presence of blowholes or porosity in the weld metal, and the penetration of the weld metal into the base metal. Two specimens are required, and a penetration of between 25 and 40 percent below the surface of the base metal is desired in materials ⅛ inch or thicker, although the penetration may be greater for the thinner sections.

d. The qualification test with the exception of the three tube joint or an alternate joint may be omitted for welders who have been employed by a contractor continuously and actively in the welding of aircraft assemblies for a period of 3 or more years, unless the procuring agency requests full compliance. The design of the test specimens for the qualification test may be modified provided the contractor obtains approval of designs equally satisfactory to the procuring agency.

e. The three tube joint used for sectioning and etching represents a combination of light and heavy sections quite often found in aircraft fitting. The contractor may substitute a fitting which represents the same general characteristics. This fitting may be selected

from a number made during the regular production, and fittings which have been welded and later rejected for some other reason than welding defects may be used in making the test.

f. Examination of welds may be performed by radiography in lieu of sectioning, provided it has been demonstrated that the technique established for examination will give a positive indication of defects.

g. A welding procedure must be installed and properly maintained, which permits a continuous record of a welder's workmanship. The minimum examination permissible under this specification is a check once each 6 months. This periodic test should be on the three tube joint (fig. 87④) and the procuring agency must be furnished with two copies of the welder's certificate as well as the results of all subsequent tests.

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